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COINDS/80/2009-10

Comprehensive Industry Document on Electric Arc & Induction Furnaces

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Central Pollution Control Board
Ministry of Environment & Forests
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March, 2010

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COMPREHENSIVE INDUSTRY DOCUMENT SERIES:
COINDS/ 80/2009-10

COMPREHENSIVE INDUSTRY DOCUMENT ON ELECTRIC ARC & INDUCTION FURNACES

Central Pollution Control Board
Ministry of Environment & Forests

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(भारत सरकार का संगठन)
पर्यावरण एवं वन मंत्रालय
Central Pollution Control Board
(A Govt. of India Organisation)
Ministry of Environment & Forests

FOREWORD

The Central Pollution Control Board (CPCB) brings out publications entitled "Comprehensive Industry Document series (COINDS)" based on the industry-wise studies. These documents are intended to cover various aspects of different categories of industries in the country with respect to their number, locations, capacities, types of product, usage of raw materials, process adopted, pollution generation, waste minimization, pollution prevention & control measures; and formulation of Minimal National Standards (MINAS). The present report entitled "Comprehensive Industry Document on Electric Arc & Induction Furnaces" is latest one in this series being published by CPCB.

The study for the report was conducted in association with Punjab State Council for Science & Technology, Chandigarh. The help and assistance extended by the State Pollution Control Boards and industries during the conduct of this study is gratefully acknowledged. Sh. J. S. Kamyotra. Member Secretary led the team of Shri U. N. Singh, SEE, Shri R. C. Saxena, SEE and Ms. Pavithra L. J. AEE, in preparing this volume.

It is hoped that this document would be useful to the secondary steel making industries, regulatory agencies, consultants and others interested in pollution control.

S. P. Gautam
Chairman,
Central Pollution Control Board

March 31, 2009

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CHAPTER I – INTRODUCTION

1.1 Introduction:

Ever since discovery of steel, it has arguably proved its versatility as a material with a wide range of critical applications over and over again. No longer is it just a material that is inevitably used to build large bridges and huge structures. On the contrary, over the years, it has come to be the officially acknowledged as a gauge for a country's development as also as an engine of its growth. Be it something as trivial as safety pin or as sophisticated as an automotive body, steel has found its unique application in all spheres of our lives as a material.

1.2 Primary Vs Secondary Steel Industry

Primary steel making industries are those where steel is made through Blast Furnace /Basic Oxygen Furnace (BOF) using iron ore. The secondary steel industry is that which makes steel through electricity. Worldwide, there are broadly two major categories of steel players:

- Integrated Steel manufacturing
- Mini Steel mills/secondary producers

From the melting of the steel to rolling to final product, the processes are carried out in integrated steel plants. Steel manufacturers therefore prefer this method due to inherent advantages –

- Lower energy cost
- Higher labor productivity because of elimination of intermediate processing and handling.
- Superior quality.
- Consistency and higher material yield
- Less Waste.

With the time, electric furnaces are favoured over other type of furnaces for steel making. The factors responsible for this transition are:

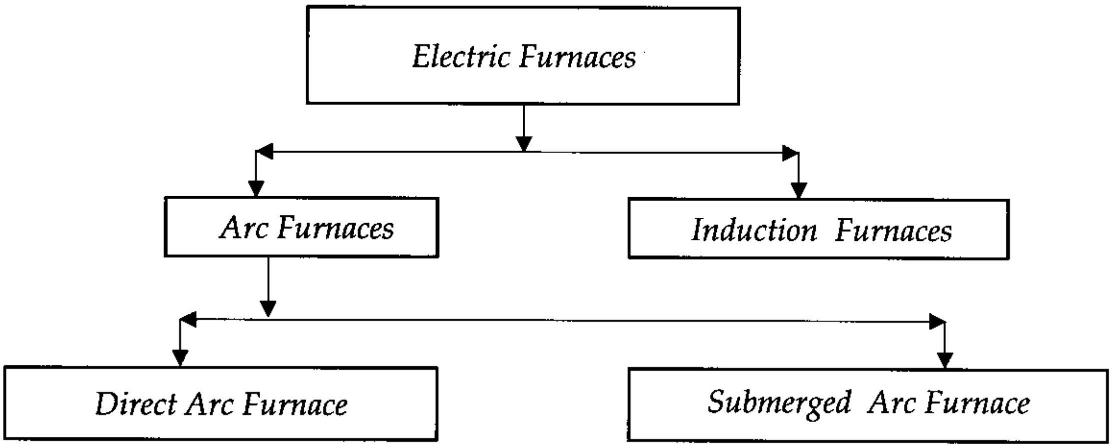
- Producing high temperatures as compared to other furnaces.
- Allowing quick rise and control of temperatures.
- Electric furnaces enable concentrated heating.
- No energy is spent to heat the fuel in case of fuel fired furnaces.

- Lower exhaust gas losses as compared to conventional furnaces.

1.3 Classes of Electric Furnaces

The mini Steel segment/secondary producers comprise mainly two classes of furnaces based on their electricity producing technology, apart from other manufacturing units like the independent hot and cold rolling mills, re-rolling mills ,galvanizing and tin plating units, sponge iron producers and so on. which are as:

- Electric Arc Furnaces (EAFs)
- Electric Induction Furnaces (IFs)



The EAF/IF units use scrap and sponge iron as raw material to produce steel. To a large extent, the integrated mills and the mini mills differs only in the technology for making molten steel. After the casting unit, both integrated steel plants as well as mini steel plants use the same steel processing method. These producers have difference in technology because of different:

- Product mix
- Management Styles
- Scale of Operations
- Process Economics
- Cost Structures
- Profitability

1.4 Raw materials used

The various raw materials used by this industry are:

- Steel–Stainless Steel Scrap, Mild Steel scrap, Sponge Iron

- Electrical Energy.

1.5 Production Capacity

In India, production of steel through electric route increased from 25% of the total steel capacity in 1982 to 46% in 2003. In India, there are 34 EAFs based steel units with a total installed capacity of around 12.5 million ton per annum. The production capacity of these units was 4.5 million ton in 1999-2000. There are 900 IFs based steel units with a total installed capacity of 10 million ton per annum. These units produced 8.5 million tones during the year 2003-2004.

1.6 Major Clusters

The major clusters of EAF/IF are:

Ludhiana/Mandi Gobindgarh/Faridabad/Delhi–North

- Belgaum/ Coimbatore/Palaghat – South
- Durgapur/Hoogli–East
- Pune/Thane/Nasik–West

CHAPTER II–ELECTRIC ARC FURNACES

Section 1: Introduction

1.1 Direct Arc Furnaces

In the Direct Arc Furnaces, electric arcs are formed between the electrodes and the metal being heated, which is thus a component of the electric circuit and is heated by the radiation from the arcs. Direct arc furnaces are used to produce high carbon steels and low alloyed steels.

1.2 Submerged Arc Furnaces

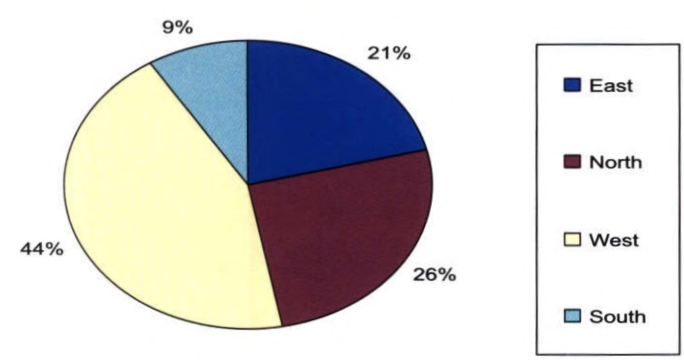
In the submerged arc furnaces, the arcs burn under a cover of solid charge which surrounds the electrodes. The charge is heated by the heat generated by the arcs and by joule heat formed on the passage of the current through the charge. SEAF is used for manufacturing ferrosilicon, ferromangenese, ferrochrome and silico-manganese alloys.The SEAFs are open from the top and the raw materials are being fed from the storage bins through chutes. These storage bins contain different grades of raw materials and are being fed in to the SEAF depending upon the properties of the finished product. In these furnaces, carbon electrodes are used to create the electric arc. These furnaces are continuous in operation but molten metal is being drawn intermittently.

In India, most of the electric arc furnaces are using Direct Arc furnaces.

Section 2: Industrial Scenario

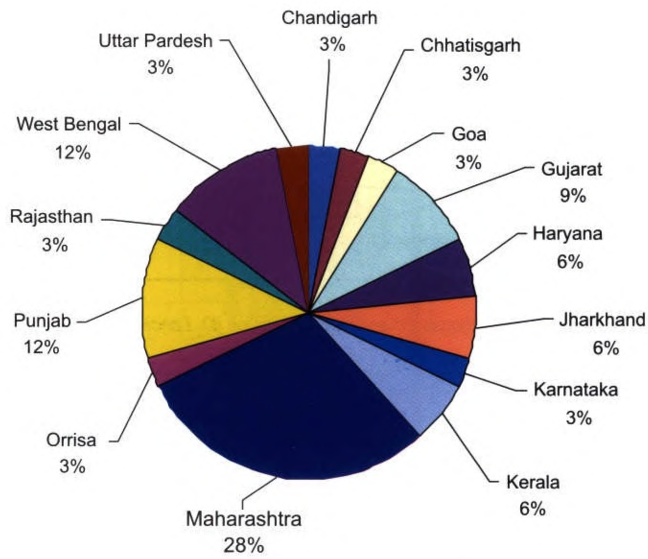
2.1 Distribution of EAFs in the country

The following charts represent the state wise and region wise distribution of EAFs.



Total No. of EAFs=34

Status of EAFs-Regionwise



State wise distribution of EAFs

Section 3: Manufacturing Process

EAF are principle melting/refining units of mini steel plants producing carbon, alloy, special steel and stainless steel for flat or products having long length applications. The processes used in these units is divided into following major steps :

- Preparation and charging of raw material
- Melting and Refining of the melt.
- Casting of molten metal into ingots, blooms and billet

The process flow chart showing various process steps used in an Electric Arc Furnace is given Fig. 1.

The EAF is a batch-melting furnace consisting of a large bowl shaped refractory lined body with a dish shaped hearth. Typically the shell diameter is 2 to 4 m. The shell has a refractory lining inside. The reaction chamber of the furnace is covered from above by a removable roof made of refractory bricks held by a roof ring. The furnace has a main charging door and a tap hole with a tapping spout. It is fed with a three phase alternating current and has three electrodes fastened in electrode clamps which are connected by means of a sleeve led flexible cables and water cooled copper tubes. The furnace rests on two supports sectors which can roll on the furnace stand to tilt ping. The tilting motion being affected by a rack mechanism. The furnace is covered by a refractory roof, which has ports for three graphite electrodes. The electrodes are supported by arms, which allow movement up and down.

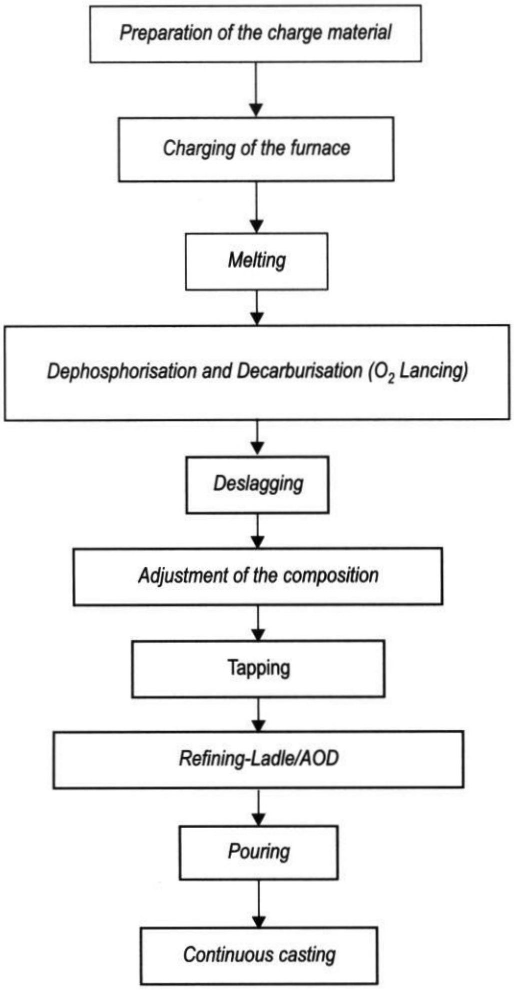


Fig: Manufacturing Process

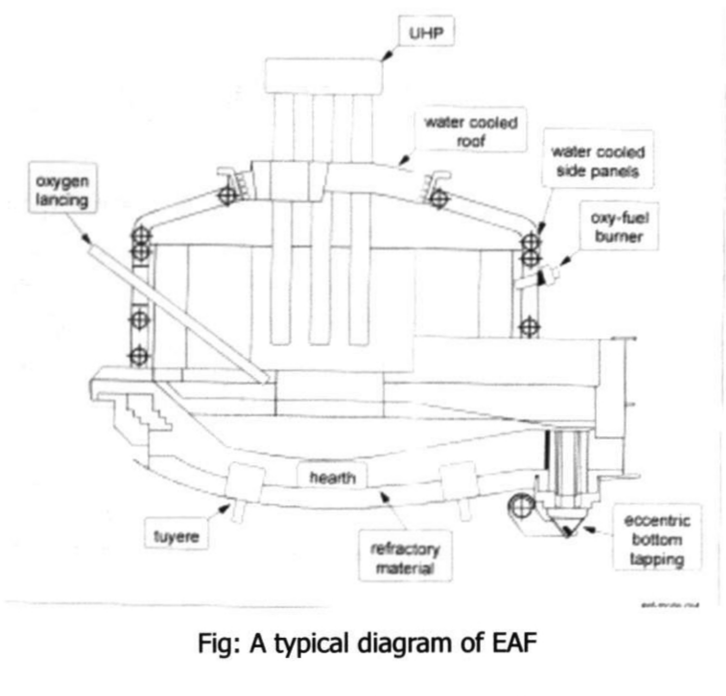


Fig: A typical diagram of EAF

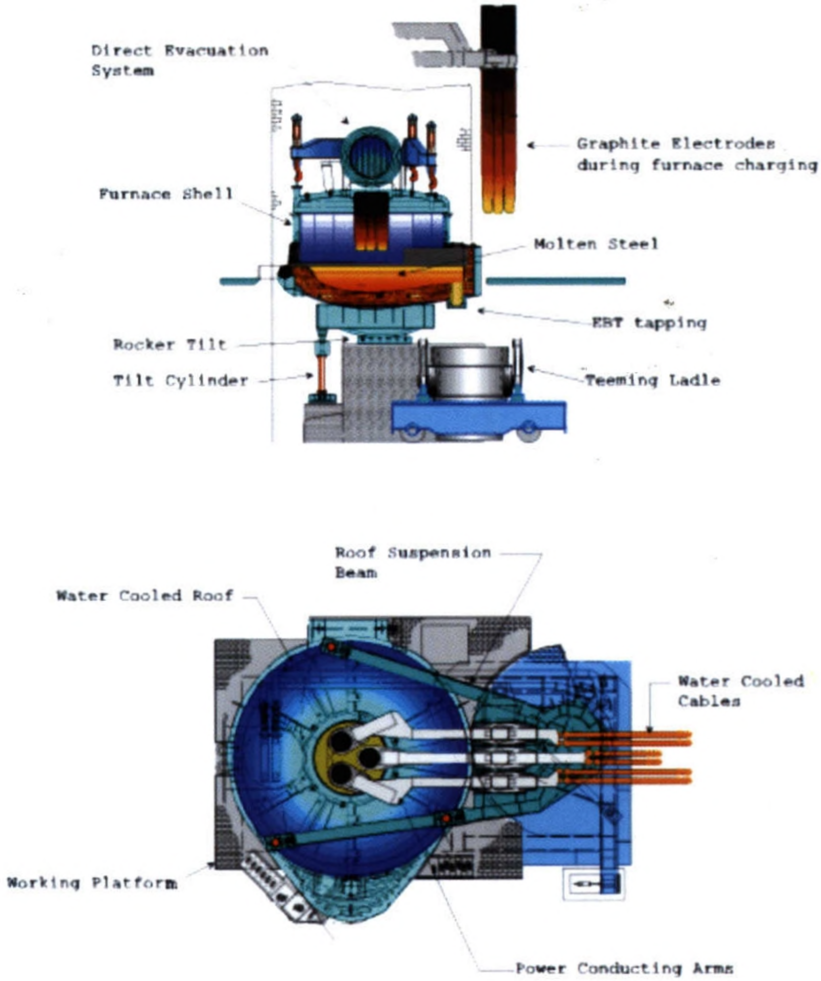


Fig: Elevation and Plan of EAF

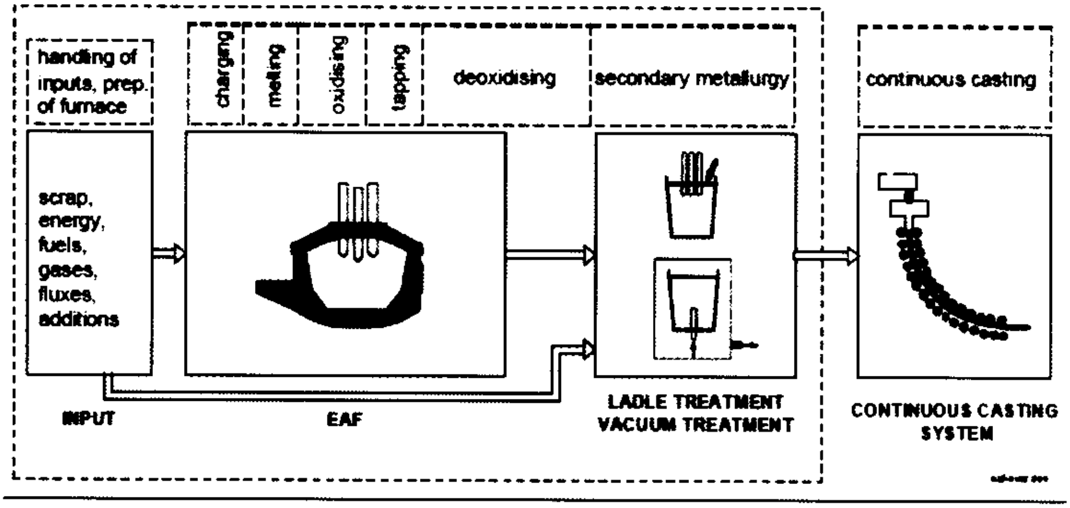
3.1 Inputs to Electric Arc Furnace

The two major inputs to an electric arc furnace to get the desired product are:

- Raw Steel
- Energy

Input	Output
Ferrous material (Steel, scrap, foundry returns, swaft, pig iron...)	Metal alloy (steel) Dust (metal content refractory)
Alloying metal (ferro alloy)	NO_x CO_2,CO
Flux (Lime stone ...)	Organic air pollutants, HC
Energy (electricity, gas, oil)	Metal oxide fumes
Oxygen	Slag (CaO_2, SiO_2, MgO)
Electrodes	Waste refractories

✓



Flow Diagram of EAF process

3.1.1 Raw materials

Raw materials and operating practices affect EAF efficiency and yield. The traditional EAFs were using 100 % cold scrap. With the time the industry has shifted towards using mix input i.e steel melting scrap, sponge iron and cast iron. The steel melting scrap is process scrap, old and discarded steel articles and components of machinery and ship breaking scrap. Turning and boring mill cut ends of billets/rods and shredded scrap are used. The shift is towards the enhanced use of sponge iron as it does not contain impurities i.e. copper and other alloying elements, melts faster and ease to control the chemistry of melt. The reasons for this transition are:

- The availability of scrap needed to meet these requirements is limited to prompt scrap. The scrap needed is imported from the international market.
- Yield and energy consumption are both strongly dependent on the quality and physical characteristics of the iron units available.

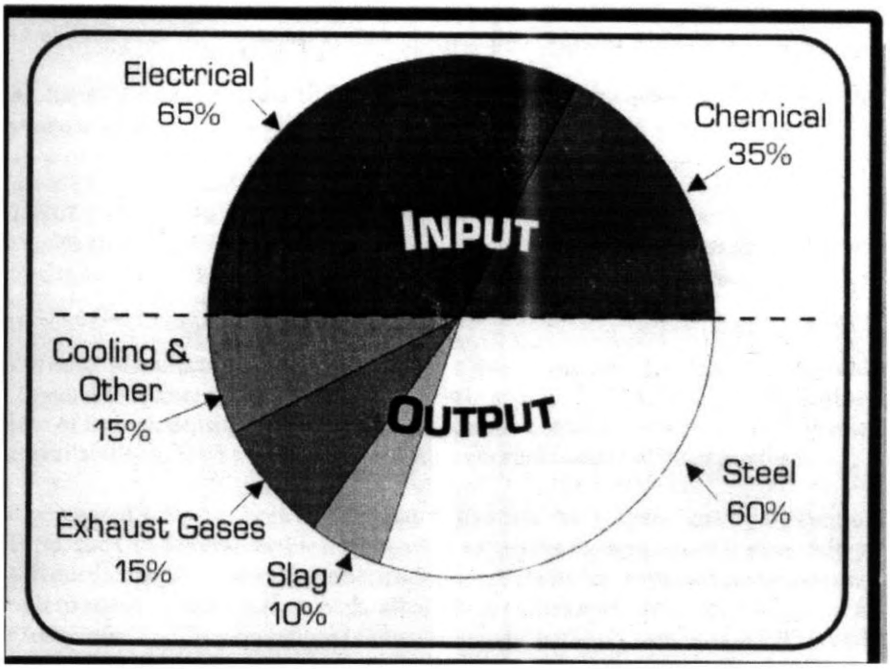
3.1.2 Energy

Productivity is function of net rate of energy input. There are two major components of energy which is put into the furnace i.e. Electrical Energy and Chemical Energy.

Electrical energy is dominant on the input side. For making one ne of steel, the energy requirement is 450-650 KWH depending upon the type of raw material used. 50-60 % of the total cost of production is of electrical energy. There are losses of this energy due to poor quality of power supplied i.e. variation of voltage and frequency, trippings during melting of metals. Thereby it becomes necessary to conserve heat by minimizing heat loss per minute during the EAF process. The production can be increased with the application of good transformer having high useful power and by reducing heat loss.

Chemical energy is concurrent with the electrical energy input and thus supplement it to reduce the heat time. In this case, oxygen injections plays an important role in combustion of oxidants in the furnace. Oxygen injection/lancing helps to burn the oxidants in the furnace and release the chemical energy in the furnace.

Around 35 % of the total energy needed in the furnace is covered by chemical energy.



A pie chart showing energy input vs output

3.2 Preparation of Raw material

The various qualities of metal feeds are stored in separate areas in order to allow the controlled feeding of the melting furnace. Raw materials, including fluxes in lump and powder form, deoxidants and refractories are normally stored under cover.

Sizing of scrap is important to maximize bucket density, better capacity utilization and minimizing energy losses. Proper scrap sizing limits the number of required recharges, thereby saving energy lost during roof swings and minimizing refractory damage due to impact of heavy pieces at charge and flare of uneven charges. The metal charged in the melting furnace is carefully selected and weighed to ensure the correct composition. Some scrap sorting is carried out to reduce the risk of including hazardous contaminants. The scrap is loaded into charging baskets in the scrap-yard or may be transferred to temporary scrap bays inside the melting shop. In some cases the scrap is preheated in a shaft or on a conveyor. The physical and chemical characteristics of the scrap have a direct influence on the performance of EAF meld shop and its operating cost. Hence the scrap type and price is crucial to the economies of Electric Steel Making.

3.3 Charging of Raw Material

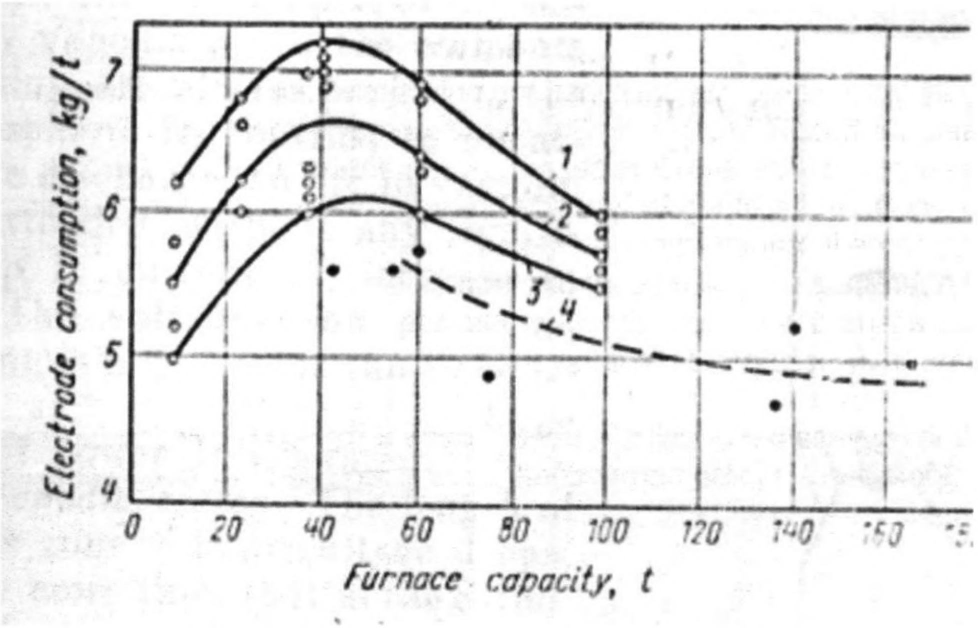
The scrap is usually loaded into buckets together with lime or dololime which is used as a flux for the slag formation. Lump coal is also charged at some plants. There are two main methods of charging of the arc furnaces i.e. box charging and pan charging. Most of the industries are using pan charging as box type charging in applicable in small furnaces. In the pan charging, charge is loaded from a pan into the furnace from the top. With pan charging, the charge of average density can be loaded in one go in 5- minutes. The roof of the furnace is swung aside at the time of charging. The capacity of the pan is selected for an average charge density of 1.0–1.2 ne/m3 . It is normal to charge about 50–60% of the scrap initially with the first scrap basket; the roof is then closed and the electrodes lowered to the scrap. After the first charge has been melted the remainder of the scrap is added from a second or third basket. Some systems also permit continuous scrap charging. However in India usually charging by means of buckets is applied.


Charging of Raw Materials

3.4 Melting and Refining of the melt

After the charging of the material into the furnace, the graphite electrodes are lowered down into the charge and the current is supplied to them. The electrodes serve to supply the electric current into the melting space of arc furnaces. The cost of electrodes per steel amounts to 10 per cent of the total production cost. The high temperature of the electric arc melts the charge beneath the electrodes, the molten metal flows down and accumulates in the lowest middle part of the hearth. As the electrodes are being lowered down, they cut wells in the charge 30-40 percent larger then the diameter of the electrodes. Usually the electrodes comes to their lowermost position 30 minutes after switching on the current .Once the first charge melts, second batch can be added to the furnace.

During operation in a furnace, the electrodes are burnt gradually owing to the oxidation by the furnace gases and atomization by the electric arc. As an electrode becomes shorter, it should be immersed more deeply in the furnace. After some time, it has to be replaced as can no longer maintain arc. The electrode consumption per tonne of steel varies from 3-10 kg.



Graph showing electrode consumption per tonne of steel

3.4.1 Addition of Lime and Coke

- Lime and other materials are added to the charge during the melting in the furnace so as to facilitate the formation is slag. The slag entraps various impurities i.e scale and rust from the melt. Foamy slags are desirable in the furnace as:
- It reduces the heat losses from the furnace.
- There is fast heating of the melt as the slag covers the surface.
- It saves from refractory from deterioration.
- It covers metal from cooling, saturation with gases and carbonization of electrodes.

The average slag formation from a electric arc furnace is 10-15 %. The composition of the slag is as:

Compound	Average (%)	Range (%)
SiO2	36.2	28.6 – 41.8
CaO	12.4	7.2 – 17.7
MgO	22.1	18.3 -27.0
Al2O3	8.4	7.4 – 0.1
FeO	0.7	0.5 – 1.0
MnO	14.8	4.0 – 29.6
TiO2	1.2	0.39 – 2.7
Na2O	0.3	0.11 – 0.57
K2O	0.1	0.1–0.23

3.5 Oxygen lancing

Oxygen in electric furnace steelmaking not only beneficial for metallurgical reasons but also for increasing productivity requirements. Oxygen for metallurgical reasons is used for decarburisation of the melt and removal of other undesired elements such as phosphorous, manganese, silicon and sulphur. In addition it reacts with hydrocarbons forming exothermic reactions. Oxygen injection results in a marked increase in gas and fume generation from the furnace. CO and CO_2 gases, extremely fine iron oxide particles and other product fume are formed. Oxygen is added to the furnace to burn the CO as excessive levels of CO can result in explosion besides wastage of useful heat.

3.6 Deslagging

After the charge is completely melted, the foam slag is taken out from the charging door. The furnace is tilted to an angle upto 15 degrees and the molten slag is taken out.

3.7 Tapping

There are two main methods of tapping the molten metal from the furnace.

- Side tapping
- Eccentric Bottom Tapping

Side tilting mechanism are employed with smaller capacity furnaces and is mounted on a column at the furnace side. In this system, the furnace has to be tilted to angle as high as 45 degrees. The limitation of this kind of system is that the removal of liquid metal from the furnace is not 100 % thereby effecting the yield.

In the eccentric bottom type tapping, the furnace rests on 2 to 4 supports sectors which roll on a horizontal stand. The spout end is made to protrude far from the furnace. In this system, tilt angle upto 15 degrees is required and this system is very effective. Most of the industries are switching over to this technology because of high yield. In this system, liquid steel with minimum slag carry over goes into the ladle.

Inputs			Outputs		
Scrap	Kg/t	1,080-1,130	Steel Melt	Kg/t	1,000
Total Energy	Kwh/t	650–750	Slag	Kg/t	100 -150
- Electrical Energy	Kwh/t	345–490			
- Oxygen	m3/t	24–47			
Graphite electrodes	Kg/t	3-10			
Lime	Kg/t	30-80			
Coal	Kg/t	13–15			

Specific Input/Output balance of typical EAF plants

3.8 Secondary Metallurgy

Secondary metallurgy covers the processes and treatment of molten steel after the tapping of the primary steel making furnace up to the point of casting. It is typically carried out at ladle treatment stations/AOD. These stations in bulk steel production plants are usually located around a vacuum generation system or arc heating unit. Other minor stations are based on inert gas or powder injection equipment. Various techniques for refining of metal are :

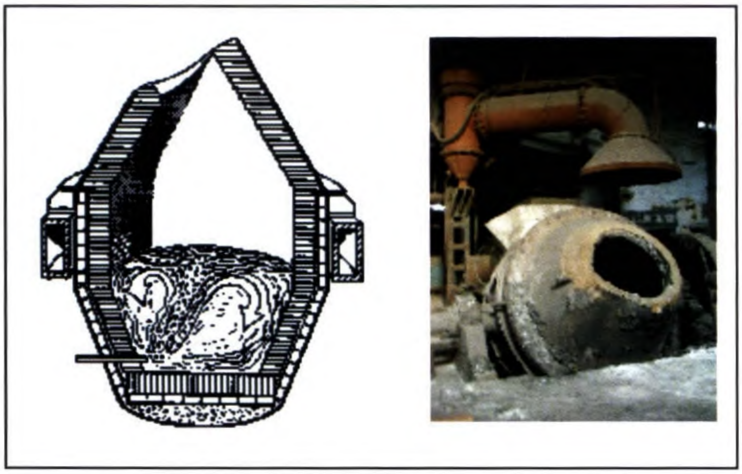
- Ladle Refining Furnace
- Argon Oxygen Decarburization (AOD)

3.8.1 Ladle Refining Furnace

Ladle refining refers to the metallurgical processes that occur in the ladle. These include alloying, deoxidizing, degassing and the reheating and stirring of the bath. Ladle refining affords the steelmaker with the flexibility to control the processing of heats in order to achieve greater production efficiencies and superior metallurgical traits.

3.8.2 Argon Oxygen Decarburisation (AOD) Converter for Steel Refining:

The AOD converter is a special vessel for refining steel. It is mainly used for the production of low carbon stainless steel The molten metal is transferred directly from the melting furnace (generally electric arc or induction) into the converter. As shown in figure, oxygen (for the removal of carbon, silicon) and argon gas (for the stirring action) can be injected into the converter by means of tuyères positioned in its lower part, to refine the metal. The converter is equipped with a tilting mechanism in order to allow filling and emptying. Steel with a precise chemistry can be produced using AOD, but at a high cost.



AOD USED FOR REFINING

The first phase of the refining process consists of a decarburisation, through the injection of oxygen into the converter. This is a refining operation that holds the carbon content of the charge material within a specific range, as required. Decarburisation is initiated by injecting oxygen into the metal bath. This creates a strong stirring action during which carbon in the melt is burned. At the same time the "boiling" burns out silicon, and flushes out hydrogen and nitrogen from the metal bath. All impurities (oxides) are trapped in the slag. During melting, lime may be added to bring the slag to the proper basicity. When the carbon reaches the required concentration, oxygen injection is stopped and silicon and manganese are added to halt the boiling reaction, especially in the production of stainless steels. A dilution of the oxygen with argon or nitrogen assists the oxidation of carbon in preference to metallic elements such as iron, chromium, etc., leading to very good metallic yields. Consequently Al or Si and limese are added to the metal and argon is injected in order to remove sulphur. The continuous gas injection causes a violent stirring action and an intimate mixing of slag and metal which can lower sulphur values to below 0.005%. The residual gas content of the treated metal (hydrogen and nitrogen) is very low. All impurities are trapped in the slag and removed with it. After temperature and alloy adjustment the metal is transferred to ladles for pouring.

Compound	Consumption (per ne of steel)
CO	50 – 120 m^3
O2	25 – 60 m^3
Al	1 – 2.5 kg
Lime	10 – 20 kg
Si	1 – 2 kg
Ar	1 – 5 m^3

3.8.3 Vacuum Oxygen Decarburisation Converter (VODC) for Steel Refining:

The VODC (Vacuum Oxygen Decarburization Converter) operates in such a way that molten steel is contained in the converter, which is attached to vacuum pumps, steam ejectors and an argon gas source. Two distinct processes are carried out in the vacuum treatment of stainless steel to obtain a higher quality level. VODC involves decarburization under reduced pressure. This process is used for making special grade steels. The VODC allows the production of ultra-low-carbon and nitrogen grades. The technique consumes 1 Nm^3 Ar per ne of steel, shows low chromium oxidation and has a silicon consumption of 3 – 5 kg/tone.

First, the steel is decarburized by introducing oxygen into the melt. At the same time, some argon is injected from the converter base. The converter uses vacuum pumps to lower the partial pressure of carbon monoxide, to such an extent that effective decarburization can be carried out without oxidising too much of the chromium. This first process is similar to AOD decarburization, but less argon is needed thanks to the lower total gas pressure and the process is much more efficient. The oxidized chromium is reduced back to liquid steel with aluminum.

The second process involves degassing. The converter is brought under deep vacuum (1–5 mbar) using a water ring pump and steam ejectors. Slight argon bubbling is continued in order to maintain an effective steel movement. At the very low pressure, gaseous impurities such as hydrogen and nitrogen are eliminated effectively. At the same time, the total oxygen content and the sulphur content are drastically decreased, which is beneficial for the mechanical properties of the end steel. Low alloyed steels are normally only degassed.

The VODC process provides specific steel qualities, which cannot be obtained by other methods. The total oxygen content is also lower than what is typical for electric arc melted and AOD-treated steel, because a high level of oxide inclusions are removed form the melt during the VODC process, and most of the dissolved oxygen is further removed during the degassing phase.

In operation since	1995	1994	1995
Furnace type	DC UHP furnace	DC UHP furnace	DC UHP furnace
Produced steel grades	carbon steel	carbon steel	carbon steel
Tapping weight [t]	100	125	120
Nominal apparent power of current transformer [MVA]	140	130	120
Raw materials	scrap	scrap	scrap
Cooling system	water cooled side walls and roofs	water cooled side walls and roofs	water cooled side walls and roofs
Tapping system	EBT	EBT	EBT
Capacity [t/a]	750,000	600,000	600,000
Additional burners	gas burners	oxygen gas burners	oxygen/natural gas burners (7)
Additional fuels	coal	coal	coal
Emission collection measures	2ndhole, hood	2ndhole, roof hood	2ndhole, ladle furnace dedust-ing, big furnace enclosure

Off gas cleaning system	post combustion chamber with additional burners quenching (air) fabric filter	post combustion chamber with additional burner quenching (water) fabric filter	post combustion fabric filter
Energy aspects	recovery of waste gas heat	recovery of waste gas heat	water cooled ducts
Secondary metallurgy	ladle furnace vacuum degassing	ladle furnace vacuum degassing	ladle furnace

3.9 Continuous Casting:

The liquid steel is usually cast continuously. Ingot casting is also still applied for some grades and applications. Continuous casting is a process which enables the casting of one or a sequence of ladles of liquid steel into a continuous strand of billet, bloom, slab, beam blank or strip Steel is tapped from the ladle into a tundish from which it is distributed at a controlled rate into water-cooled copper moulds of appropriate dimensions.

To prevent the solidified shell from sticking, the mould is oscillated in the direction of casting at speed greater than the casting speed and a mould lubricant is added in powder form or vegetable oil. The strand is continuously withdrawn and is further cooled using direct water sprays. At a point where solidification is complete the strand is cut to required lengths using automatic oxygen cutters.

The prerequisites for the production of electric steel are the provision of the inputs scrap, additions, fluxes, and electrical energy, as well as the regular preparation of the furnace, i.e. its lining with different types of refractory material to protect the furnace shell against high temperatures and chemical and physical strain caused by inputs, heat, and slag.

The charging of the furnace is usually performed in batches: Two to four buckets with, possibly sorted, scrap are inserted through the open top into the furnace. Each charge is partly melted while the next bucket is prepared. Some systems also permit continuous scrap charging, however, in India usually charging by means of buckets is applied. According to the desired steel quality, fluxes (e.g. lime) and additions (e.g. carbon, chromium) are also added. The addition of these materials can take place both during the charging step and the oxidation step, if the furnace is equipped accordingly. To melt the charged inputs, the movable roof is closed, the graphite electrodes (introduced through the roof) are lowered, the electric arcs are ignited, and the melting phase starts. To lower the consumption of electrical energy and to accelerate the melting process, oxygen or a fuel-gas mixture can be injected by special types of lances or by oxy-fuel burners to generate process heat.

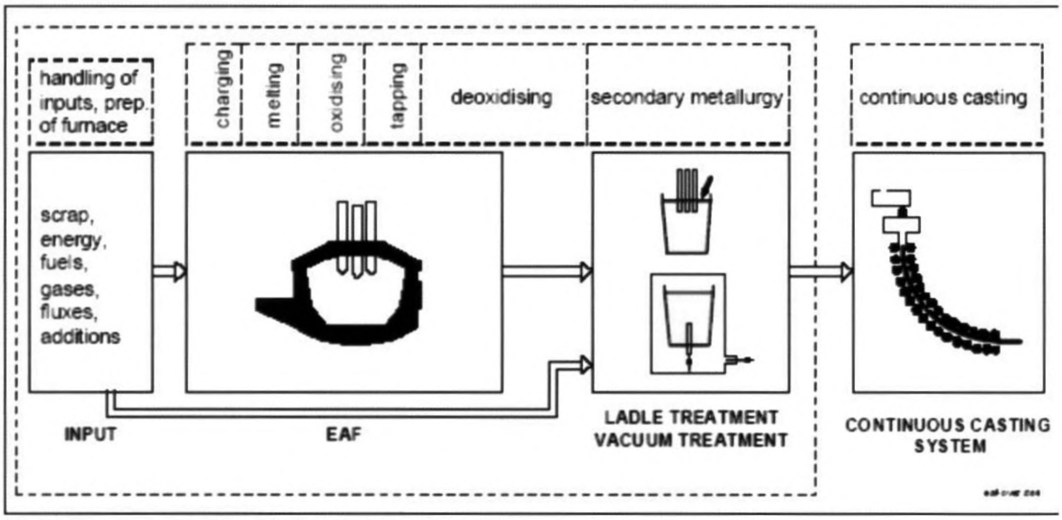
The oxidation step normally starts after the melting is completed. It mainly aims to reduce the carbon content of the heat and to oxidise undesired tramp elements. During the melting and the oxidation phase a slag is formed on top of the heat. The slag helps to remove tramp elements like sulphur, silicon, phosphor, and manganese. Besides this positive metallurgical effect, a foamy slag on top of the melt is also important for achieving an efficient energy transfer and in particular the protection of the furnace shell. Another positive effect of the foamy slag is a reduction in noise caused by the EAF process. Usually, at the same time as the injection of oxygen, also pulverised coal, or so-called foaming coal, is injected by lances into the furnace to intensify the boiling. Stirring and bath agitation may also be supported by the injection of inert gases (e.g. argon or nitrogen) by means of tuyeres.

The tapping step starts with the tilting of the furnace to tap the slag, as the highly oxidized slag is not desired in the following secondary metallurgy processes. Then the raw steel is tapped at temperatures of about 1,600 to 1,680°C. The tapping angle required to almost empty the furnace varies from 12° to 42°, depending on the tapping system. In practice, eccentric bottom tapping (EBT) is commonly used nowadays. This system allows a slag free tapping and tapping angles of about 12°, which are favourable for cost savings (caused by the reduction of tap-to-tap times, reduction of heat losses, shorter power cables).

In general, secondary metallurgical processes, e.g. in a ladle furnace, follow the tapping step. Some refining may also take place in the EAF itself, but nowadays the fine adjustment of the desired steel quality is not performed in the EAF. The secondary metallurgical treatment of the steel melt in an extra vessel was established for the increasing demands on the steel quality, requiring additional post-melting treatment, and the possibility of reducing tap-to-tap times by using the EAF only for the melting of steel.

Break-Up of the Total Cycle Time of a 25t Furnace:

OPERATION	MINUTES
Charging	2-3
Melting	120-130
Oxygen Lancing	10-20
Deslagging	10-15
Pouring	3.5
Total Cycle Time	145



Schematic Diagram of EAF manufacturing process

Section 4: Sources of Pollution

4.1 Air Emissions from Electric Arc Furnaces

The emissions from EAFs originate from the charging, melting, and refining operations and during tapping of the furnace.

During charging, dust and dirt will be emitted from the open furnace body. When charging a hot furnace (for instance when melting with a molten heel in particular), any combustibles such as grease, paint or oil ignite and give rise to smoke plumes of burnt and partially burnt organic material and dust particles. The mechanical abrasion of the furnace lining also generates additional dust.

During melting, heating of the scrap generates metal oxide fumes that significantly increase during the decarburisation treatment. The injection of oxygen gas into the molten metal develops significant quantities of iron oxide fumes, which leave the furnace as red clouds. The addition of slag forming materials increases the furnace emission, but only in small quantities and only for a short time. Minor emissions occur during the transfer of the molten metal into a ladle or holding furnace. Emissions from the melting operation itself are referred to as primary emissions. Secondary emissions are the fumes and dust originating from the charging and tapping.

As per the literature, particulate emissions rates vary from 6- 20 kg/tonne of charge with an average of 10–12 kg/tonne. The highest emission rates are recorded at the beginning of the melt cycle and during the decarburisation treatment. The composition of the dust primarily depends upon the grade of the steel being produced. The available literature does not report the quantities and the composition of the secondary emission being generated during charging, tapping and de-slagging operations. The nature of these emissions depends on the cleanliness of the raw material w.r.t. oil, grease, paint etc.

Emission – Charging

Emission–Annular Spaces Around Electrodes

Emission – Deslagging

Emission–Tapping

4.2 Air Emissions from AOD:

Dust emissions from AOD are comparable to EAF furnaces dusts, both in quantity and quality. AOD dust emissions have lower levels of residuals (organic) from the scrap charge, but on the other hand have a higher level of metal oxide (Cr, Ni), as it is mainly stainless steel which is processed in AOD vessels.

The effluent from the mouth of an AOD consists of carbon monoxide and inert gas. The rate of carbon monoxide evolution depends on the tuyères oxygen injection rate and the oxygen efficiency, or per cent of oxygen which reacts with carbon. This oxygen efficiency, or "carbon removal efficiency", as it is traditionally labeled in AOD operation, varies during the course of an AOD blow, in response to combined variables of the bath carbon level, temperature, bath chemistry, and the mixture of injected gases.

The CO and inert gas mixture leaves the vessel approximately at the bath temperature. The CO mixture exiting the vessel is mixed with excess air in order to fully burn the CO to CO2 very early in the exhaust duct. This is done to prevent the presence of combustible or explosive mixtures persisting downstream into the duct to the filter equipment.

4 .3 Submerged Electric Arc Furnace (SEAF):

This is one of the other types of electric arc furnace working on the same principle. SEAF is used for manufacturing ferrosilicon, ferromangenese, ferrochrome and silico-manganese alloys. The capacity of these furnaces varies from 20-60 T/day. The raw materials used are ores of these alloys, coal, coke, dolomite, quartz etc.

In SEAF, silica is reduced by carbon in the presence of iron. The rest of the carbon will be consumed to transform silica to silicon carbide. Mass and enthalpy balances are used to determine the carbon and electricity requirements of the process. The recycling of silicon monoxide is promoted by maintaining a bed of a certain height so that evolved gases are cooled owing to heat exchange between the gas and solid phases.

The SEAFs are open from the top and the raw materials are being fed from the storage bins through chutes. These storage bins contain different grades of raw materials and are being fed in to the SEAF depending upon the properties of the finished product. In these furnaces, carbon electrodes are used to create the electric arc. These furnaces are continuous in operation but molten metal is being drawn intermittently.

Section 5: Field Study Results

A comparative statement of the industries visited for the purpose of study is as under:

North

The electric arc furnaces in this region are located in Ludhiana, Mandi Gobindgarh, Chandigarh and Faridabad.

S. No.	Description	Unit A	Unit B	Unit C	Unit D	Unit E	Unit F
1	No, of furnaces	1	1	1	2	1	2
2	Melting Capacity (T/ heat)	30	30	25	25 each	10	15 each
3	Heat time (in minutes)	135	120	270	140-150	180-210	210-240
4	Tapping system	EBT	Side Tapping	Side tapping	Side tapping	Side tapping	Side tapping
5	Power Consumption	EAF-725	515	900	525	500-600	530
	(KwH/T)	LRF-130	87	125-150	-	65-150	150-200
		Aux- 70	90	100-125	-	100-125	-
6	Transformer rating (MVA)	16	20	5.5	9	4.15	6
7	Raw material						
	Sponge Iron-	70-80%	50%	75%	40-45%	10%	-
	Pig Iron, HMS & Plant returns	20-30%	30%	25%	55-60%	65%	-
	Others		20%			25%	
8	Graphite electrode consumption (Kg/T)	3-4	2.9	3-4	3.2	3.6	3.75
9	Technology for air pollution control	Pulsejet bag filter	Pulsejet bag filter	Reverse air bag filter	Pulsejet bag filter	Pulsejet bag filter	Reverse air bag filter
10	Type of containment	Swinging 4th hole elbow evacuation	4th hole evacuation	4th hole evacuation	4th hole evacuation	Swinging 4th hole elbow evacuation & Roof extraction system	4th hole evacuation
11	Supplier of APCD	M/s Thermax Ltd., Pune	M/s. Thermax Ltd. Pune	M/s. Nikko Tech., Mumbai	M/s. Thermax Ltd. Pune	M/s. Thermax Ltd. Pune	M/s. Nikko Tech., Mumbai

12	Flue gas volume (including LRF) (in Nm3/hr)	54000	58000	118800	60000	35000	62500
13	Fan pressure (mm) and	485	500	600	600	500	-
	Motor rating (kw)	75	200	345	150	56	500
14	Flue gas cooling arrangement	Air to air heat exchanger	Air to water heat exchanger	Dilution damper	Air to water heat exchanger	Air to water heat exchanger	Spray scrubber
15	Capital cost of APCD (Rs. in Crores)	2.0	2.0	1.5	2.2	0.80	2.5
16	Dust generation (% of production capacity)	0.5%	1.3%	1.5%	0.38%	1.35%	1.2%
17	Slag generation (% of production capacity)	12.96%	8-9%	10%	5-7%	5.5%	10-12%

EAST

Sr.No.	Description	Unit G
1	No, of furnaces	2
2	Melting Capacity (T/heat)	15T each
3	Heat time (In minutes)	240
4	Tapping system	Eccentric Bottom Tapping
5	Power Consumption (KwH/T)	750
6	Transformer rating (MVA)	7.5 (including LRF)
7	Raw material	
	Sponge Iron-	5-10%
	Scrap	90-95%
8	Graphite electrode consumption (Kg/T)	7 (including LRF)
9	Technology for air pollution control	Cyclonic scrubber followed by Bag filter
10	Type of containment	Canopy hood with pneumatic swivel arrangement
11	Supplier of APCD	Designed by the industry itself
12	Flue gas volume (including LRF)	27000 m3/hr (at 5000C)
13	Fan pressure (mm) and motor rating (kw)	—
14	Flue gas cooling arrangement	Water cooled duct
15	Capital cost of APCD (Rs. In Crores)	—
16	Dust generation (% of production capacity)	—
17	Slag generation (% of production capacity)	—

WEST

Sr.No	Description	Unit H	Unit I	Unit J	Unit K	Unit L	Unit M
1	No. of furnaces	1	1	1	1	1	1
2	Melting Capacity (T/heat)	48	40	20	45	50	30
3	Heat time (in minutes)	120	90	240	70	100	150
4	Tapping system	Side tapping	Side tapping	Side tapping	EBT	EBT	EBT
5	Power Consumption (KwH/T)	—	—	—	—	458	—
6	Transformer rating (MVA)	20	21	7.5	36	36	18
7	Raw material						
	Sponge Iron-	15%	—	20-25%	20%	25-30%	40-50%
	Pig Iron	20-25%	—	30%	25-30%	10%	
	HMS, Scrap, Scull etc.	60-65%	75-80%	50%	40-50%	40-50%	
8	Graphite electrode consumption (Kg/T)	2.5–2.8	2.7-2.8	2.5-3.0.	3.60	2.8	3.5
9	Technology for air pollution control	Pulsejet Bag filter	Reverse air bag filter	Reverse air bag filter	Pulsejet Bag filter	Reverse air bag filter	Reverse air bag filter
10	Type of containment	4th hole evacuation	4th hole evacuation	4th hole evacuation	4th hole evacuation	4th hole evacuation	4th hole evacuation
11	Supplier of APCD	M/s Thermax Ltd., Pune	M/s Nikko Techs, India	M/s Nikko Techs, India	M/s Flakt India Ltd.	M/s Nikko Techs, India	M/s Nikko Techs, India
12	Flue gas volume (including LRF) (In Nm3/hr)	1,08,000	90,000	38,000	90,000	—	90,000
13	Fan pressure (mm) and	880	550	20kg/cm2	900	—	—
	motor rating (kw)	388	315	410	336	350	150
14	Flue gas cooling arrangement	Cooling duct & Natural cooled ducts	Cooling duct & Air to Air heat exchanger	Cooling duct	Cooling duct & Air to Air heat exchanger	—	Cooling duct
15	Capital cost of APCD	2.65	2.50	—	—	2.30	3.0
	(Rs. In Crores)						
16	Dust generation	1.8T/day	5T/day	1.0T/day	—	—	1T/day
17	Slag generation (% of production capacity)	12.5	4-5	10	—	8%	8-10%

Specific Input/ Output balance of typical EAF plant

Inputs			Outputs		
Scrap	Kg/t	1,080-1,130	Steel melt	Kg/t	1,000
Total energy	Kwh/t	650-1150	Slag	Kg/t	100-150
Of that: Electrical energy Oxygen	Kwh/t m3/t	450-900 20-30	Dust	Kg/t	5-15
Graphite electrodes	Kg/t	2.5-4.0			
Lime	Kg/t	30-80	Refractory breaks	Kg/t	n.a.
Coal	Kg/t	13-15	Plant scrap	Kg/t	n.a.
Lining	Kg/t on average	1.9-25.1 8.1	Noise	dB(A)	125-139
Water	Closed loop				

SUBMERGED ELECTRIC ARC FURNACES (SEAFs)

Sr. No.	Description	Unit N	Unit O	Unit P
1	No. of Furnaces	4	3	3
2	Production Capacity	80TPD from 4 furnaces	100 TPD from 3 furnaces	110 TPD from 3 furnaces
3	Finished product	Si-Mn alloys High carbon (Si-16%,Mn- 60% Iron-21%, C- 3%) Medium Carbon (Si-25%, Mn- 55% Iron-19.5%, C- 0.5%)	Fe-Cr alloys	Fe-Mn and Si-Mn
4	Tap to tap time	2.5 hrs per heat	2 hrs. per heat	Fe-Mn (2 hrs) Si-Mn (2.5hrs)
5	Transformer rating	3.5 MVA (2 nos.) 7.5 MVA (2 nos.)	7.5 MVA each	5.5 MVA, 6.5 MVA and 12 MVA
6	Raw material composition	Mn ore – 64% Quartz- 3.5% Dolamite – 1.5% Fe-Mn slag – 17% Coal/coke -14%	Ore -2.6T/Tof alloy Coke -0.8T/Tof alloy Fluxes-0.2T/Tof alloy	Mn ore- 30-46% Coke- 70-75% Dolamite -250kg/T for Fe-Mn
7	Power consumption (Kw/ton)	5000(medium carbon) 4000(High carbon)		
8	Slag Generation	40 TPD from all the 4 furnaces (high carbon) and 25 TPD (medium carbon)	15000T/annum from all the 3 furnaces	1Ton per ton of metal
9	Ultimate disposal of slag	Land filling	Dumping in storage yard	The slag of Fe-Mn used as raw material and slag of Si-Mn dumped in low lying areas

10	Technology for Air pollution Control	Venturi scrubber	Pulsejet bag filter	Cyclone followed by Pulsejet bag filter for 5.5 MVA & 6.5 MVA and scrubber for 12 MVA
11	Capacity of APCD	80,000 m3/hr. for each furnace Pressure- 400 mm	1,00,000 m3/hr (3500C) Pressure- 350 mm Motor-100 hp	
12	Dust generation	4.5 TPD from 4 furnaces		90 kg/day from 6.5 MVA furnace
13	Disposal of dust	The dust contains Mn-20%, C-30%, Iron-5%, ash 40%. The dust after briquetting is used as raw material.		
14	Capital cost of APCD	80 lacs for all the 4 furnaces	1.50 crores for 3 furnaces	-

There are around 11 sub merged electric arc furnaces in Durgapur manufacturing Ferro-silicon, Ferro- manganese, Ferro- chrome and Silico-manganese alloys. Each unit on an average is having 3 submerged electric arc furnaces with capacity varies from 20-60 ton/day. The raw materials used are ores of these alloys, coal, coke, dolomite, quartz etc.

In submerged electric arc furnace, silica will be reduced by carbon in the presence of iron. The rest of the carbon will be consumed to transform silica to silicon carbide. Mass and enthalpy balances are used to determine the carbon and electricity requirements of the process. The recycling of silicon monoxide is promoted by maintaining a bed of certain height so that evolved gases are cooled owing to heat exchange between the gas and solid phases.

The submerged electric arc furnaces are open from the top and the raw material is being fed from the storage bins through chutes. These storage bins contain different grades of raw material and are being fed into the furnace depending upon the properties of the finished product. In these furnaces, carbon electrodes are used to create the electric arc. These furnaces are continuous in operation but molten metal is being drawn intermittently.

Most of the units have provided hoods at a distance of 1.2-1.6 m from the top of the furnace to contain the dust emissions followed by air pollution control device in the form of venturi scrubber/bag filters Unit N has provided side suction hoods. This design was found to be good in comparison to other furnace as the industry has provided shutters in the gap between the furnace and the hood to cover it to the maximum possible extent. The shutters are operated for pushing of the raw material by motorized trolley and for electrode removal. The hood is supported on brick masonry structure.

Observations

Capacity and Tap to Tap time

The economical furnace size is limited by the power transformer size and the power the electric supply grid can provide. The following table shows relation among capacity, required size and electrical equipment. The melting rate depends largely on the capacity of the transformer as seen from the following table:

Nominal capacity of furnace (10^3kg)	Outside diameter of furnace core (m)	Metal bath depth (mm)	Diameter of electrode (mm)	Capacity of transformer (MVA)			Secondary voltage (RP furnace) (V)
				RP	HP	UHP	
2	2.178	300	175	1.5	-	-	180/80
5	2.743	400	200-250	3	5	-	200/100
10	3.353	400	300-350	5	7.5	-	220/100
20	3.962	450	350-400	7.5	12	15	240/100
30	4.572	650	400-450	12	18	22	270/120
50	5.182	750	450-500	18	25	30	330/130
60	5.486	850	500	20	27	35	400/130
70	5.791	850	500	22	30	40	400/130
80	6.096	900	500	25	35	45	430/140
100	6.400	950	500-550	27	40	50	460/160
120	6.706	1000	550-600	30	45	60	500/200
150	7.010	1000	600	30	50	70	500/200
170	7.315	1050	600	35	60	80	500/200
200	7.620	1100	600	40	70	100	560/200
400	9.754	1200	700	-	-	150	—

Notes: RP: Regular power, HP: High Power, UHP: Ultra High Power

Source: Cast Product Hand Book, 4th Edition, Japan Cast Product Association

The capacity of the furnaces studied during the visit varies from 9 T/ heat to 48 T/ heat. The tap to tap time varies from 70 minutes – 270 minutes. The tap to tap time depends upon the availability of power supply and the capacity of the transformer. A unit having a transformer capacity of 36 MVA for their 45T furnace has tap to tap time of 70 minutes whereas another unit having a transformer capacity 6.5 MVA for 22 ton furnace were having a tap to tap time of 270 minutes.

Because of electric power supply limits, electric power costs and furnace efficiency considerations, oxygen, natural gas and coal are increasingly used to augment the melting process. The most powerful furnaces approach a power – to – tapped steel weight ratio of 1 MVA per ton.

Segregation of Scrap

Most of the furnaces are segregating their scrap before charging into the furnace. This would help in to avoid explosions due to presence of some explosive material in the scrap such as bomb shells.

Composition of Raw Material

The desired steel quality is a relevant factor for any resulting impacts of electric steel production on the environment, as different types of steel grades require different input compositions and generally different treatments cause changes in the yield and chemical composition of dusts and slag. It has been observed that the composition of the raw material i.e. sponge iron, pig iron, HMS, shredded scrap, plant scrap etc. varies within the industry, industry to industry and region to region depending upon the availability of these materials in the market and their cost.

Electric steel making plants use scrap of various grades and qualities usually consisting of a mix of old, new and plant scrap depending upon the quality of steel to be produced. The plant scrap arises during production and further processing of crude steel within plant limits. New scrap arises during the manufacture of finished products while old scrap denotes scrap returning after utilization of finished products. It has been experienced that the quality of the scrap being used by the industry varies to a great extent depending upon its availability in the market and its cost.

Tapping System

Most of the electric arc furnaces have side tapping but the furnaces being commissioned in the recent past have eccentric bottom tapping system that discharges the molten metal vertically into a ladle placed underneath the furnace by a transfer car.

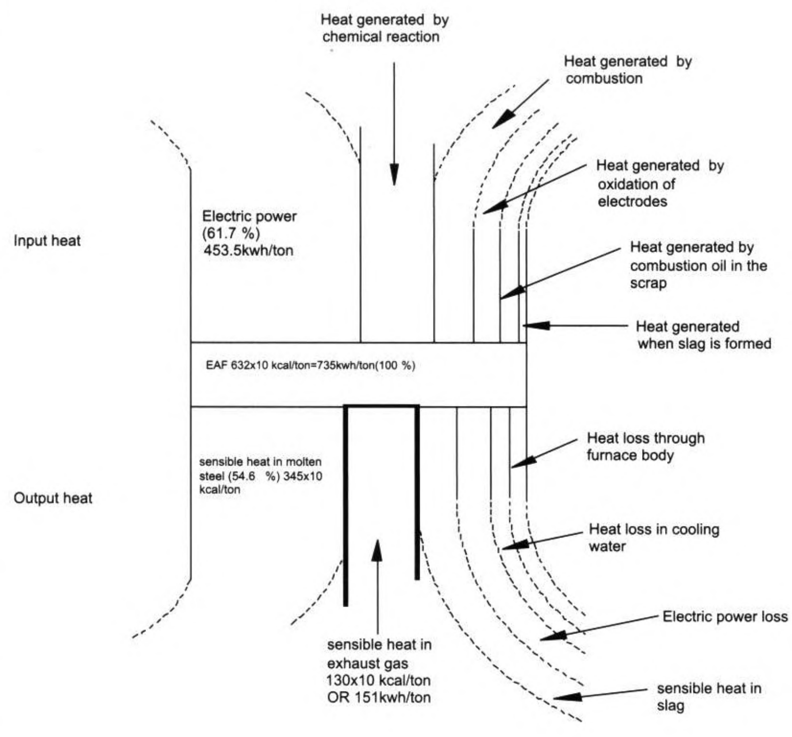
Foamy Slag Practice

Most of the furnaces now-a-days are using Foamy Slag Practice by injecting carbon powder into the furnace.

Energy efficiency

Electric arc furnace is only 55% energy efficient with 45% of the total furnace energy input going into losses such as slag (10%), water cooled panels (12%), the off-gas system (21%) and miscellaneous other losses (2%).

Sr. No.	Description	(%)
1	Energy utilized in melting	
	Heat of molten metal	27.16
	Heat of molten slag	6.28
2	Losses	
	Structural losses	3.32
	Cooling water losses	29.02
	Radiation heat loss through electrode hole	1.25
	Radiation loss through slag hole	7.75
	Radiation during charging of furnace when lid is open	5.59
	Heat loss in exhaust gases	19.63
	Total	**100**



E.A.F. HEAT FLOW CHART

The structural losses and losses in cooling water depend on the duration of heat. Whereas the radiation losses through slag hole and charging of furnace can be reduced by simple house keeping measures. The heat wasted in exhaust gases can be recycled for the preheating of scrap.

Power Supply

Most of the electric arc furnaces in operation in the country are supply AC power to the arc using three graphite roof electrodes. Most of the DC furnaces are single electrode units where the current flows down

from the carbon electrode which serves as a cathodes to an anode in the bottom of the furnace. A few DC furnaces are of three electrode type where the current flows from each of the top electrodes to a bottom return electrode.

The electrode consumption in case of DC arc furnace is 50-60% lower than that of conventional three phase AC furnace. Electrical consumption can be 3-5% lower than AC operation. It is also reported that noise level of the DC furnace are lower and lower maintenance cost are claimed due to lower refractory cost. Capital cost of DC installation are higher than AC system, however reduced operating cost can recoup this difference. The equipment needed for DC melting has the same configuration as that of a conventional

AC furnace. The exceptions are the addition of the bottom electrode (anode), DC reactor and thyristor rectifier.

Use of Ladles

Most of the electric arc furnaces are using 2-4 ladles for the transfer of molten metal from electric arc furnace to ladle refining furnace and from ladle refining furnace to concast plant. It was observed that one unit in Punjab is using only one ladle in the whole process upto to concast plant thereby avoiding the emissions being generated during pre-heating of the ladles with furnace oil beside savings on account of consumption of furnace oil.

Pre-heating of scrap.

Pre-heating of scrap is a practice to tap the waste heat in the exhaust gases. Scrap pre-heated to a temperature of 600-7000C leads to reduction in tap to tap time by 8-10 minutes and a saving of 30-40 kWh/t in electrical energy. This would need to reduction in dust emissions in the flue gas.

The literature reveals that the waste gas contain energy content upto 150 KwH/T of which more than 80 KwH/T can be chemical energy. During the project studies, it was observed that one of the units had explored the viability of heating the scrap through waste gases. The industry achieved reduction in energy consumption by 25-30 kWh per ton of steel produced with a capital investment of Rs. 50.0 lacs whose present value is around Rs. 1.5 crores. Presently the industry is not practicing the pre heating of scrap because of following practical problems:

- ✓ Difficulty in taking out the pre-heated raw material from the pre-heating chamber thereby resulting in production loss.
- ✓ The system is only viable for units using 100% shredded scrap as other raw materials such as turning and boring and sponge iron gets partially melted in the pre-heating chamber. This would result in chocking of the system.
- ✓ Excessive pressure drop across the pre-heating chamber thereby requiring more energy to suck the emissions from the furnace.
- ✓ May be due to the formation of organic emissions
- ✓ May be due to the formation of dioxins
- ✓ May be due to the non control over the temperature in the scrap pre heater. However, this option has to be evaluated thoroughly with respect to economic viability.

Containment of air emissions

The emissions from the electric arc furnace are mainly of three types:

- Primary emissions
- Secondary emissions
- Fugitive emissions

The primary emissions are produced in the electric arc furnace during melting and possibly during the refining periods in the secondary metallurgy vessels. The secondary emissions are the emissions being

generated during charging, heat tapping, slag tapping and opening around the electrodes. Whereas fugitive emissions being generated during various raw material handling operations such as receiving, unloading, storing and conveying.

It has been experienced that majority of the electric arc furnaces have provided 4th hole evacuation to contain the primary dust emissions which contributes 90% of the total emissions as per the literature. Most of the furnaces do not have any arrangement to contain the secondary as well as fugitive emissions whereas in one of the furnaces , it has been studied that the secondary emissions contributes 30% of the total average cycle time of 120 minutes. The secondary emission as well as fugitive emissions escape into the furnace building and are vented through the roof vents.

One industry at Haryana have installed Roof extraction system on the EAF in addition to 4th hole evacuation to contain the secondary dust emissions. Further Unit A & E have installed swinging duct connecting water cooled elbow and water cooled duct to combustion chamber which swings with the movement of electric arc furnace thereby capturing the dust emissions being generated during de-slagging and tapping period. Another industry have provided swiveling canopy hood above their electric arc furnace in place of 4th hole evacuation to contain the primary as well as secondary dust emissions. The hood is being operated pneumatically and is 5-6 feet below the overhead crane and around 2 feet above the top of the graphite electrodes thereby not hampering any of the furnace operations.

Cooling Arrangements

The gases from the electric arc furnace after entering the combustion chamber have temperature anywhere between 500-8000C. These gases have to be cooled before taking to the bag filter. Normally the bag filter operates at about 1200C. The gases can be cooled by following ways.

- Dilution
- Water cooling heat exchanger
- Air cooling heat exchanger

Each of the above has its own advantages and disadvantages. If we cool the gases by dilution as observed in one of the units, the gas volume becomes very high i.e. 1,20,000 Nm3/hr for their 22T furnace. The power consumption of the fan becomes very high i.e. 350Kwh. The other option is to cool the gases in a water cooling heat exchanger which has the highest heat transfer coefficient i.e. between 25 to35. The capital cost is lower and the cooling was reported to be very effective. Water cooling heat exchanger has got the advantage that the whole unit is very compact and economical in running. Air cooling heat exchangers are comparatively bigger in size and the heat transfer coefficient is anything between 10 to 15. Number of blowers are used for cooling the incoming hot flue gases. This system has the advantage of switching off a number of blowers whenever the temperature of the flue gas was observed to be low thereby savings on account of energy consumption. Moreover there are less operational problems because it does not have any interconnecting water cooling pipes, cooling tower and pump. The capital cost of water cool heat exchanger is 75% of that involved in air cooling heat exchanger.

Further it has been observed that Unit H has provided natural cooling of the duct by vertically extending it around 500 ft in U shape pattern to bring down the temperature of the flue gas. The photographs of the cooling arrangement are shown below:

Natural cooling of the flue gas (Fig.1)

Natural cooling of the flue gas (Fig.2)

Flue gas Volume

It has been observed that the volume of the flue gas of electric arc furnace with matching ladle refining furnace varies from 2300-4500 Nm3/hr per ton capacity of the furnace.

Air Pollution Control Measures

Most of the electric arc furnaces have installed the following technology to control the pollution being generated from the electric arc furnace.

- Reverse air bag filtration
- Pulse Jet bag filtration

Most of the air pollution control systems having reverse air bag filtration technology were designed and supplied by M/s Nikko technologies, Japan, whereas the system having pulse jet bag filtration technology were designed and supplied by M/s Thermax Ltd., Pune. Both of these technologies are efficient and adequate to achieve the emission standards of 150 mg/Nm3 prescribed by the Central Pollution Control Board.

It has been observed that in case of reverse air bag filter, there is no exhaust chimney for venting the clean gases after filtration thereby making it impossible to collect the samples for checking the PM. The clean gases after bag filtration are being released from the louvers provided in the side walls of the shed. The total height of the bag filter was observed to be around 20-25 m. Some of the observations made for both the technology are detailed below:

Sr. No.	Reverse air bag filtration	Pulse jet bag filtration
1	The fan is located before the bag house and is designed to operate with dust laden gases. This would result in low efficiency of the fan thereby higher power consumption	The fan is located after the bag filter and is designed to operate the clean gases. The efficiency of the fan is more with less power consumption.
2	Low air to cloth ratio would result in more bag area.	High air to cloth ration would result in smaller bag area.
3	Life of the filter bags is long. Retaining rings are stitched into the filter bags and hence the filter does not come into contact with each other.	Life of the filter bags is short because of contact with cage and each other
4	Checking of the filter bags during operation is always possible from clean gas side as dust setting is on the inner side of the filter bag.	Checking of the filter bags is always from dust attaching side i.e. dust deposition on the outer side of filter bag and hence no inspection is possible during operation.
5	Filter bags can be replaced within the bag house during operation	Cage housing the filter has to be taken out for replacing the filter bags. Consequently, plant has to be shut down for change of bags.
6	Compressed air is required at 5kg/cm2 for bag filter cleaning.	Compressed air is required at 5-7 kg/cm2 for proper and effective cleaning of the bags.
7	As a part of exhaust gas is only used for reverse draft, the power consumption for fan is about 30-40 KW.	As a separate compressor is required, the additional power consumption is 100-150 KW.

One electric arc furnace have installed cyclonic scrubber followed by bag filter to control the pollution from their 15T furnace. The operation and maintenance of the bag filter is very important otherwise the bag filter would result in increased pressure drop, reduced suction and consequent bypassing of the bag house. The bag cleaning operation should always be off line. It has been observed in some of the industries that the pulse jet bag filter cleaning is online because of to reduce the capital cost of the equipment. It is experienced that the industries are not maintaining the proper maintenance schedule regarding:

- Manometer readings at regular intervals to check the pressure drop across the bag filter.
- Checking of the bags at regular intervals.
- Checking of the solenoid valves.
- Time periods for the disposing off the dust from the bag filter
- Checking of the ID fans
- Record for the replacement of bags

Dust generation

The electric arc furnace dust is collected from the bag filters. The following factors are mainly responsible for dust generation:

- Transformer rating
- Quantum of oxygen used.
- Product mix
- Amount of carbon in the charge
- Quality of scrap

It has been observed that the average rate of dust generation varies between 5-15 kg/T. An average electric arc furnace of 30T capacity with production capacity of 270TPD generates about 400T of dust per annum. The industry is dumping this hazardous dust either within the industry or in the low lying areas. No industry was found to have any metal recovery system. Some of the industries have constructed the dedicated sheds to store this dust after filling it in HDPE bags. The composition of the dust varies to a great extent depending upon the product mix and the quality of the scrap. The analysis of the dust carried out by CPCB and various other agencies are tabulated below:

Sr. No.	Description	*Concentration (mg/g)
1	Cd	0.188
2	Cr	0.740
3	Cu	1.060
4	Fe	428.50
5	Ni	0.124
6	Pb	15.500
7	Zn	192.00

*Source: CPCB

Sr. No.	Description	Nikko Techs, India (%)	SAIL, Ranchi (%)	Metallurgical & Engg., Consultants India Ltd., Ranchi (%)	Thermax Ltd., Pune (%)
1	Iron oxide (Fe2O3)	25-30	19-60	19-65	40.5
2	Calcium oxide(CaO)	2-12	2-22	1-22	3.03
3	Silica (SiO2)	10-20	1-9	2-14	4.07
4	Zinc Oxide (ZnO)	20-35	0-44		
5	Lead oxide (PbO)	3-4	0-4		
6	Managese oxide (MnO)	2-5	3-12	4-12	31.41

7	Magnesium oxide (MgO)	2-4	2-15	2-38	10.0
8	Nickel oxide (NiO)	3-5	0-3		
9	Aluminium oxide (Al2O3)	1-2	1-13	1-13	8.0
10	Chromium oxide (Cr2O3)	9-12	0-12		
11	Molybdenum oxide (Mo2O3)	0.5-1.0			
12	FeO	—	4-11	2-8	
13	Fe	—	5-36		
14	P	—	0-1		
15	S	—	0-1		
16	C	—	1-4		
17	Alkalies	—	1-11		

Source: Proceedings of the workshops on, "Environmental Pollution in Secondary Steel Industry held at Delhi from 21st – 23rd August, 1991.

It has been seem from the above table that the composition of the dust varies with the composition of the raw material depending upon the grade of steel to be manufactured. Further it also varies with the type of scrap used, which itself varies with respect to its origin.

Disposal of dust

It has been observed that some of the industries do not have proper arrangements for the storage and disposal of dust being collected below the hoppers of bag filter house. Few industries have provided screw conveyors underneath the bag filters to collect and transport the dust into

overhead silos from where it is loaded into the trucks for ultimate disposal. It has been experienced that when we take the dust from overhead silos to the trucks, certain amount of dust flies into the environment. This problem of flying of the dust repeats again when dust is unloaded from the truck to some place. This dust is very light and fine like a talcum powder. It flies into the environment with moderates winds.

Slag generation

Like dust generation, slag generation is an indispensable part of the steel making process. Slag usually arise at two places within an electric steel making plant. In the EAF itself, an oxidizing slag is formed, furthermore a refining slag is obtained in the secondary metallurgical process. The yield and composition of secondary metallurgy slags are dependent upon the desired output. Significant differences exist between the amount and composition of the slag obtained by the production of commercial steels and high grade steel.

In electric arc furnace, slag generation varies from 100-150kg/T of steel produced. Most of the industries are dumping their slag into the low lying areas after separation of iron by the magnetic separators.

Fluid coupling with fan of APCD

Generally the fan is installed at the back end of the pollution control system consumes very large amount of power. The flue gas volume varies with variation in temperature of the furnace at different times. It has been observed that the pollution control system which was designed with respect to peak volume when comes to valley (low volume) because of variation in temperature, the efficiency of the fan comes down. The fan was observed to be operating all the time irrespective of whether the furnace was under charging or furnace was under tapping. When the fumes were not generated even then the fan was running continuously, may be with the damper partially closed but consuming fairly good amount of power.

One unit at Punjab have installed fluid coupling with the fan so that the speed of the fan can be varied according to the pollution load. As we know that volume of the flue gases is proportional to the speed of the fan, the pressure is proportional to the square of the speed and power consumption is proportional to the cube of the speed. By incorporating this system, the industry have been able to save considerable amount of energy.

Refractory Material

The total refractory material consumption generally consist of two components. One part arises by the breaking out of refractory material, another part results from continuous wear and tear and is combined with slag or dust. The total average consumption of refractory material (furnace and secondary metallurgy vessels) depends significantly on the type of steel produced. It has been observed within the following limits:

- Carbon steels – 12 kg/ton (approximately)
- High grade steels (alloyed and stainless steels)- 22-32kg/ton (approximately)

The average refractory consumption in the furnace itself amounts to 8 kg/ton of steel produced. The consumption of refractory depends on the produced steel quality, further more on the tap to tap time and the heat temperature of tapping.

Section 6: Emission Monitoring Results

During study, to the various clusters of electric arc furnaces, the following units have been identified for emission monitoring:

The performance evaluation of the technology provided for air pollution control from electric arc furnace, work zone monitoring and ambient air monitoring was carried out. The results of the monitoring are tabulated below:

Particle size distribution

Particle size range (in micron)	Northern region		Western region	Eastern region
	Unit I (A) (EAF) % of particles (Number basis)	Unit II (E) (EAF) % of particles (Number basis)	Unit III (H) (EAF) % of particles (Number basis)	Unit IV(N) (SEAF) % of particles (Number basis)
0-2	6.6	49.16	22.17	41.60
2-10	31.4	27.90	20.68	27.50
10-20	40	7.99	13.84	13.30
20-30	10	4.48	11.62	7.80
30-40	9	2.72	10.87	3.60
Above 40	3	7.75	20.83	6.80

Performance monitoring of the air pollution control system

S. No.	Description	M/s Aarti Steel, (EAF)	M/s Starwire India Ltd., Faridabad (EAF)	M/s Mohindera Ugine Steel, Raigad (EAF)	M/s Shyam Ferro Alloys, Durgapur (SEAF)	
1	Furnace capacity (T/ heat)	30	10	48	80 TPD	
2	Raw Materials Sponge iron	70-80%	10%	15%	Mn ore Quartz Dolamite Fe-Mn slag Coal/coke	64% 3.5% 1.5% 17% 14%
	Pig iron, HMS & Plant returns	20-30%	65%	85%		
	Others	-	25%	-		
3	Design Flue gas volume including LRF (Nm3/hr)	54,000	16,000	1,08,000	40,000 (for 2 furnaces)	
4	Technology for Pollution Control	Pulse Jet Bag Filter	Pulse Jet Bag Filter	Pulse Jet Bag Filter	Venturi Scrubber	

Monitoring Results

Sl. No.		Inlet		Outlet		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
		Charging	Oxygen lancing	Charging	Oxygen lancing						
1	Flue gas volume (Nm3/hr)	18432	17375	27099	31070	13853	13407	1,24,370	1,04,942	42,727	42,381
2	Temperature (0C)	280	290	62	67	129	88	145	80	190	40
3	Velocity (m/sec)	10	9.6	5.5	6.4	31.30	5.74	33.84	10.99	6.50	4.36
4	PM (mg/Nm3)	1168	817	40	37	462	35	15,520	330	140	40
5	PM (kg/tone)	1.48				1.8		64.30			
6	SO2 (mg/Nm3)	5	4.2	4	3.4	-	-	23	-	-	-
7	NOx (mg/Nm3)	12	10	8.4	8	-	-	35	-	137	-

8	CO (mg/Nm3)	112	110	98	96	12 ppm	5 ppm	16	-	189 ppm	-
9	VOC as Total hydrocarbon (mg/ Nm3	Below detectable limit									
10	Work Zone										
	SPM (8 hrly sample) (mg/m3)				6.25 -6.52		2.83		2.57 -2.59		0.78
	APCD working										
	APCD not working				-		-		-		1.73
	CO				2.85–3.11		-		-		-

Monitoring of AOD & Roof extraction system of Unit II (E).

Sr. No.	Description	APCD-AOD	APCD –Roof extraction system
1	Location	Stack after APCD	Stack after APCD (APCD not in operation)
2	Temperature (0C)	62	46
3	Velocity (m/sec)	7.14	10.79
4	Flue gas volume (Nm3/hr)	59,982	41,040
5	PM (mg/Nm3)	110	70

Monitoring of LRF of Unit I (A).

Particle size distribution

Particle size range (in micron)	% of particles
0-2	29.5
2-10	55.0
10-20	11.5
Above 20	4.0

Sr. No.	Description	APCD-LRF
1	Location	Stack before APCD
2	Temperature (0C)	105
3	Velocity (m/sec)	9.5
4	Flue gas volume (Nm3/hr)	3,366
5	PM (mg/Nm3)	1182
6	SO2 (mg/Nm3)	4
7	NOx (mg/Nm3)	8
8	CO (mg/Nm3)	90
9	VOC as T.hydrocarbon (mg/Nm3)	Below detectable limit

Ambient Air Quality Monitoring Of Unit III (H)

Sampling Stations	RSPM (micro gram/m3)	SPM (micro gram/m3)
Station 1 (Weigh bridge)		
1st sample – 12 hrs (19.00 -7.00)	178	275
2nd sample -12 hrs (7.00-7.00)	462	577
Station 2 (Main receiving station)		
1st sample – 12 hrs (19.00 -7.00)	38	188
2nd sample -12 hrs (7.00-7.00)	132	443
Station 3 (Rolling mills)		
1st sample – 12 hrs (19.00 -7.00)	129	290
2nd sample -12 hrs (7.00-7.00)	p132	274

The size of the particles varies with the variation in the composition of the raw material depending upon the product to be manufactured. It also depends upon the quality of the scrap which again varies with respect to its origin.

Observations on the monitoring results –

The monitoring results indicated in the above tables was studied thoroughly and the observations made are as under:

UNIT I (A)

It has been observed from Table that only 6.6% of the particle are up to 2 micron which seems to be on the lower side. The following observations were made after critically examine the Table 3 of performance monitoring:

- The flue gas volume monitored before bag filter as 17375-18432 Nm3/hr against design volume of 54000 Nm3/hr.
- The efficiency of the pulsejet bag filter for the control of PM was found to be around 96% during melting as well as during oxygen lancing.
- The SO2 and NOx emission before APCD was found to be in the range of 5 -12 mg/Nm3.
- The temperature of the flue gas monitored before the bag filter was found to be 280-2900C. The sample was taken before the air heat exchanger provided by the industry. The temperature at this point should be around 500-7000C as per the literature.
- The flue gas volume in the stack was monitored as 28,000- 31,000 Nm3/hr against flue gas volume of 17,375 – 18,432 Nm3/hr monitored before the bag filter. This increase in volume of the flue gas may be due to the cooling of the flue gas with air heat exchanger.

- The PM levels before the bag filter was monitored to be 817-1168 mg/ Nm3 during oxygen lancing and charging time respectively. Whereas the literature, the PM levels at the time of oxygen lancing should be more than during charging time. These emissions levels were found to be on the lower side. This may be because the industry was operating the fan at around 30,000 Nm3/hr against designed of 54,000 Nm3/ hr. These emission may be much more if the industry has operated the fan at its designed capacity i.e. 54,000 Nm3/hr.

- The SPM levels in the work zone was found to be around 6.5 mg/Nm3 during oxygen lancing stage and 6.2 mg/Nm3 during the charging and melting stage against the permissible limit of exposure (time weighted average concentration – 8 hrs) of 10 mg/ m3 as indicated by The Factories Act, 1948

- The CO levels in the work zone was found to be around 3 mg/m3against the permissible limit of exposure (time weighted average concentration – 8 hrs) indicated by The Factories Act, 1948 of 55 mg/ m3 .

- The PM level before the bag filter in case of Ladle refining furnace was monitored as 1182 mg/Nm3.

- The Volatile Organic Carbon (VOC) both in case of the electric arc furnace and ladle refining furnace before bag filter was found to be below detectable limit.

UNIT II (E)

From Table, it has been observed that 49% of the particles are up to 2 micron and 28% of the particles are between 2-10 micron. The following observations were made after studying the Table 3 of performance monitoring in light of the size of the particles:

- The flue gas volume monitored to be around 14,000 Nm3/hr against design flue gas volume of 16,000 Nm3/hr which seems to be right.

- The temperature monitored before the bag filter as 1290C seems to be right as the sample was taken after the water heat exchanger.

- The PM levels before the bag filter was found to be 462 mg/Nm3. These levels are found to be on the lower side. This may be due to the composition of the raw material (sponge iron -10%, Pig iron – 5%, Heavy melting scrap/plant returns – 60% and others 25%) as the industry is manufacturing high carbon stainless steel.

- The efficiency of the pulsejet bag filter for the control of PM was found to be around 96%.

- The CO emissions before and after APCD was found to be 12 ppm and 5 ppm respectively.

- The SPM levels in the work zone was found to be 2.83 mg/m3 whereas the permissible limit of exposure (time weighted average concentration – 8 hrs) of 10 mg/ m3 as indicated by The Factories Act, 1948 .

- The PM levels at the inlet of Argon Oxygen Decarburiser (AOD) could not be monitored as the duct before bag filter was totally water cooled.
- The PM levels monitored after the air pollution control device provided on roof extraction system to contain the secondary emission was found to be as 70 mg/Nm3. The APCD was out of operation at the time of sampling. Hence the PM levels of 70 mg/ Nm3 shall be treated as inlet levels.
- The VOC emissions were monitored at the inlet of APCD but nothing was detected.

UNIT II(H)

The 22% of the particles were monitored to be between 0-2 micron and 21% of the particles were found to be between 2-1 micron. The observations made are as under:

- The flue gas volume monitored to be 1,24,000 Nm3/hr against design volume of 1,08,000 Nm3/hr. This may be because of excess dilution.
- The temperature of the flue gas was monitored as 1450C. The sample was taken before the cooling arrangement. The temperature at this point should be around 500-7000C as per the literature. This may be due to excessive flue gas volume because of higher dilution.
- The PM levels in the flue gas were monitored to be as 15,520 mg/Nm3. This may be due to higher flue gas volume and high pressure of the fan i.e. 880 mm against average pressure of 500 mm.
- The SPM levels in the work zone was found to be around 2.6 mg/m3 whereas the permissible limit of exposure (time weighted average concentration – 8 hrs) of 10 mg/ m3 as indicated by The Factories Act, 1948 .
- The RSPM levels in one of the sampling stations at weigh bridge was found to be 178 and 462 microgram/m3prescribed standards of 150 microgram/m3 (Table 6).Whereas the SPM levels at this station was found to be 577 microgram/m3 against the prescribed standards of 500 microgram/m3.

UNIT IV (N)

Unit IV is having a submerged electric arc furnace for the manufacture of high carbon and medium carbon Si-Mn alloy. The industry has provided common venturi scrubber for two of its furnaces having capacity as 40,000 Nm3/hr. The industry is manufacturing high carbon Si-Mn (Si-16%, Mn-60%, Fe-22% and C-3%) and medium carbon Si-Mn (Si-25%, Mn-55%, Fe-20% and C-0.5%). The raw materials used are manganese ore, coal, coke, dolomite, quartz. The tap to tap time is 2.5 hours. The industry has provided side suction hoods to contain the dust emissions followed by venturi scrubber. The design of the hood was found to be good in comparison to other SEAFs as the industry has provided shutters in the gap between the furnace and the hood to cover it to the maximum possible extent. At the time of monitoring, the furnace was running at 60% of its capacity due to power failure.

The observations made are as under:

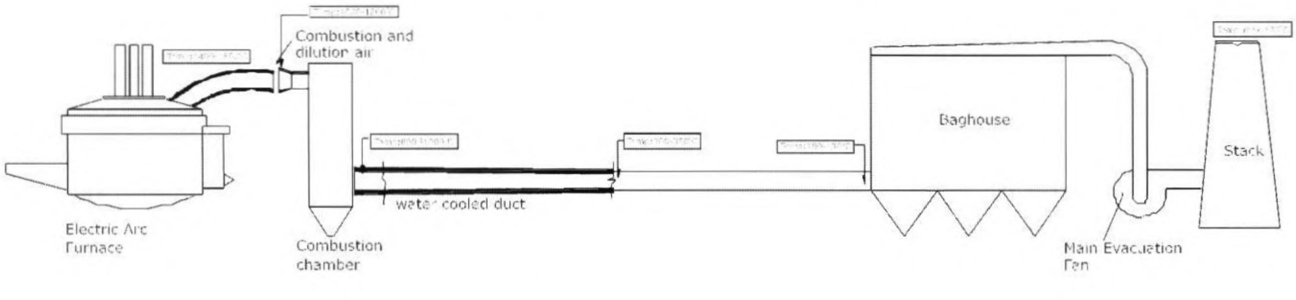
- The flue gas volume monitored to be around 42,000 Nm3/hr against design volume of 40,000 Nm3/hr. This seems to be all right.
- The PM levels before the air pollution control device was monitored to be as 140 mg/ Nm3. This seems to be on the lower side as the stack standards for the same are 150 mg/Nm3. This may be due to poor suction of the flue gases.
- The NOx and CO levels before the air pollution control device was monitored to be as 137 mg/Nm3 and 189 ppm respectively.
- The SPM levels in the work zone was found to be 1.73 mg/m3 when the APCD was not in operation and 0.78 mg/m3 when the APCD was in operation against the permissible limit of exposure (time weighted average concentration – 8 hrs) of 10 mg/ m3 as indicated by The Factories Act, 1948.

Section 7: Pollution Control Technologies

7.1 Containment of emissions

7.1.1 Fourth Hole Evacuation

Majority of the electric arc furnaces have provided 4th hole evacuation to contain the primary dust emissions which contributes to 90% of the total emissions. This type of extraction technology is state of the art in modern EAF steel making for the collection of primary emissions and is recommended. A schematic diagram showing the same is as under:



DIRECT EVACUATION SYSTEM

7.1.2 Swinging duct system

It has been experienced that in majority of the EAFs, the fourth hole elbow for the containment of dust emissions remains static. As a result, the dust emissions during de-slagging and tapping period escape the water cooled fourth hole elbow. It is recommended to install a swinging duct system connecting fourth hole water cooled elbow and water cooled duct leading to combustion chamber in the existing furnaces for the containment of dust emissions being generated during de-slagging and tapping period. The swinging duct swings with the swing of electric arc furnace at time of de-slagging and tapping operations. As a result, the emissions going out from the sheds for a period 30-40 minutes out of a total cycle time 120 minutes at the time of de-slagging and tapping operations were captured in the air pollution control device. In some of the furnaces, it stands demonstrated.

7.2 Secondary Emission Control System

Most of the furnaces do not have any arrangement to contain the secondary emissions being generated during charging of the raw material, from openings around the electrodes, tapping and de-slagging operations. These emissions would contribute only 5 to 10% of the total emissions.

It is recommended that canopy hoods by compartmentalizing the upper portion of the shed, not interfering with the overhead crane and electrodes, be installed high above the furnace to contain the secondary emissions. The roof and the sides of the sheds are sealed.

However the provision for capturing secondary emissions does not seem to be feasible in the existing furnaces because of the inadequate strength of the roof structure and movement of the over head cranes/gantry. Whereas it is worthwhile to provide for capture of secondary emissions in new furnaces proposed to be set up. A velocity of 200-250 fpm should be maintained between the furnace and the hood with duct velocity as 3500-4000 fpm.

The volume flow rates for well designed canopy hoods usually range from 2, 50,000 acfm at 1500F, depending on the furnace size. Hoods should be sized to match the rising plume at the hood face taking into account the dispersion of emissions by objects such as scrap buckets and cranes.

7.3 Air Pollution Control Technology

Most of the electric arc furnaces have either installed pulse jet bag filtration technology or reverse air bag filtration technology. The efficiency of pulse jet bag filtration was found to be between 93-98%. The efficiency of reverse air bag filtration technology could not be evaluated as most of the air pollution control system do not have stack to vent out the clean gases after bag filtration. The clean gases after bag filtration are being released through louvers provided in the vertical side walls of the shed of bag filter.

It is recommended that both the technologies i.e. reverse air bag filtration and pulse jet bag filtration are highly efficient to the tune of 99.9% and either of the technology can be used for the control of the particulate emissions. But in case of pulsejet bag filter, the cleaning of the bags should be off line. The bag filter shall be provided in compartments preferably in five compartments with 25% extra capacity so as to attend the necessary repairs/replacements without interrupting the furnace operation.

7.4 On line emission monitoring

It is proposed that the industry should provide online stack monitoring kits to monitor the suspended particulate matter in the exhaust gases. The cost of the kit is around Rs. 4 lacs.

7.5 Total cost of the APCD

Type of APCD	Capital cost (Crore)	O & M cost/ annum (Crore)	Total O & M cost/annum considering life of equipment as 7 years (Crore)
Bag Filter	2.5	0.53	0.89

The annual turnover of 30 T/heat EAF was reported to be 400 – 500 crores. The environmental cost works out as 0.2% of the annual turnover much below the limit of 3% as per the requirement of National Enviornment Policy 2006.

7.6 Collection and Disposal of dust

It has been observed that most of the industries do not have proper arrangement for the collection and disposal of dust. As a result, part of the dust flies back into the environment because of the cross currents. It is proposed that a belt conveyor covered from the top and sides shall be provided underneath the hopper of the bag filter to collect the dust through rotary feeder. This dust is being conveyed to the storage silos through conveyor belts. From storage silos, it is being filled in HDPE bags through mechanical means as like in cement plants. The stitched dust bags can be disposed off to the hazardous waste landfill sites. Alternatively the dust can also be disposed off after its pelletisation.

7.6 General

- The structure of a charging crane should be considered so as not to obstruct the ascending stream from the furnace.
- The melt shop layout has a significant influence on the design of the furnace secondary emission control system. Heat sources in a melt shop such as ladle heaters and the continuous casting area should be isolated from the electric arc furnace melting and refining area. It is because the heat from ladle heaters and continuous casting area does not contain any dust and is being emitted outside the sheds without dedusting.
- A canopy hood should be centralized without separating. Induced air through building openings should be directed to the furnace and be emitted through a main canopy with the aid of ascending stream caused by heat convection. Location of the opening at various areas of the building should be designed to eliminate stagnation points.
- Excess air infiltration into the furnace and ductwork should be reduced to the lowest level possible in order to reduce the loading to the system. A damper should be provided in DEC duct system to control the draft of the furnace.
- Cross drafts must be kept to a minimum near the furnace to prevent the emissions from being blown away from the hood.

CHAPTER III: ELECTRIC INDUCTION FUNRACES

Section 1 Introduction

Induction furnaces are used to melt both ferrous and non-ferrous metals. There are several types of induction furnaces available, but all operate by utilizing a strong magnetic field created by passing an electric current through a coil wrapped around the furnace. The magnetic field in turn creates a voltage across, and subsequently an electric current through, the metal to be melted. The electrical resistance of the metal produces heat, which in turn melts the metal. Induction furnaces are made in a wide range of sizes. Because there is no contact between the charge and the energy-carrier, the induction furnace is suited for the melting of steel, cast iron and nonferrous metals, so long as a suitable lining material can be found. Products made by the industry are as :

- Mild Steel Ingots for structural purposes.
- Stainless Steel Ingots for making utensils,wire rods and wires.
- Low alloy steel castings for engineering applications.
- Stainless steel castings for heat and corrosion resistant components.
- Alloy steels for forging industry and grinding media.
- Cast iron castings

1.1 Emergence of Electric Induction furnaces

Most of EAFs / IFs are recycling the steel scrap, as there is shortage of scrap in the country. Since early 70"s to 1985, around 150 EAFs were installed with a capacity of over 9 million tones in various parts of the country. However, in the meanwhile, Induction furnaces technology came into the country in early 80's. Induction Melting Furnaces in India having capacity 500 kg to 1 ton were first installed to make Stainless Steel from imported Stainless Steel Scrap. By 1985-86, the technology of making Mild Steel by Induction Furnace was perfected by Indian Technologists by putting up of bigger capacity furnaces. By 1988-89, 3 tones Induction Furnaces were become common in India. In 1991-92, more Induction furnaces having bigger capacity were installed all over India. Now-a-days, furnaces upto a maximum capacity of 20 ton/heat are being used. India is the only country in the World using induction furnaces on a large scale to manufacture secondary steel. .

1.2 Preference to Induction Furnaces over Electric Arc Furnaces

India is the first country using Induction Melting Furnaces for making mild steel. The bulk of structural quality mild steel for long products is manufactured by Induction Melting Furnaces. During 2001-2002 period over 4.3 million tones of steel were produced by Induction Furnaces, which has reached a level of 4.7 MT in 2002-03. The EAF units have also installed Induction melting furnaces. There are several reasons for the popularity of Induction Melting Furnaces for making steel.

- They consume less power comparing EAF's. Expenditure on electrode is nil.
- They use lesser quantity of refractory. Initial investment is less on plant and equipment. Thus, there are economic advantages in making steel through Induction Furnaces route.
- The environmental pollution in case of EAF is much more than Induction furnaces.

The only snag of steel production through induction furnace route is of capacity limitation .

1.3 Types of Induction Furnaces

There are two main types of induction furnaces.

- Iron Core Induction Furnaces
- Core Less Induction furnaces

Most of the industries are using coreless induction furnaces as this system is much more efficient as compared to Iron Core furnaces because of efficient melting and long furnace life.

The coreless IF is a batch-melting furnace containing a water-cooled copper coil, the inside of which is internally refractory lined. The outside is insulated and enclosed in a steel shell. The furnace body is mounted in a frame equipped with a tilting mechanism. A coreless induction furnace is normally a refractory-lined bucket-shape refractory, the top of which is open for charging and deslagging operations.

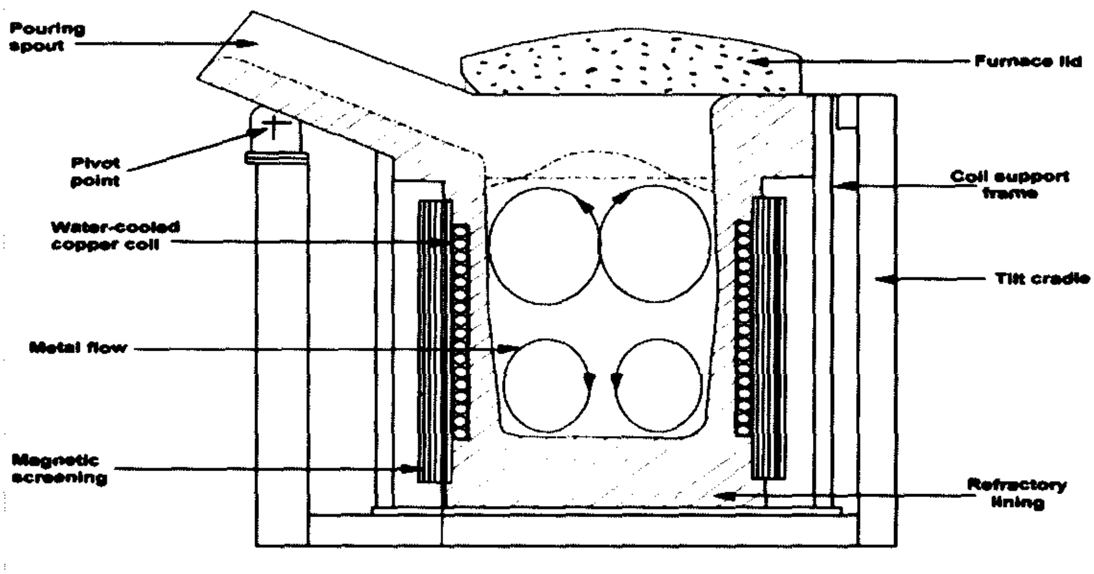
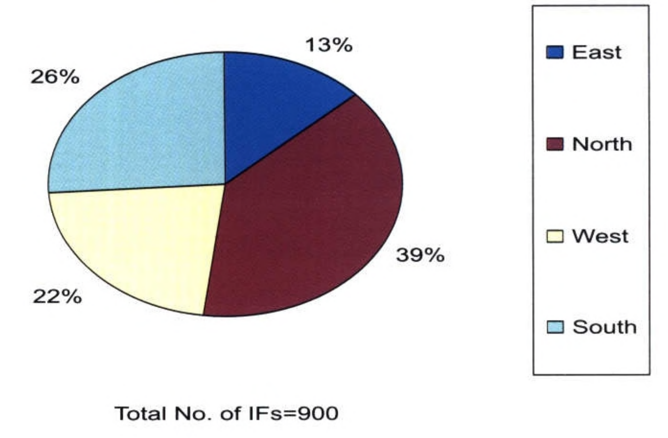


Fig. Core Less Induction Furnace

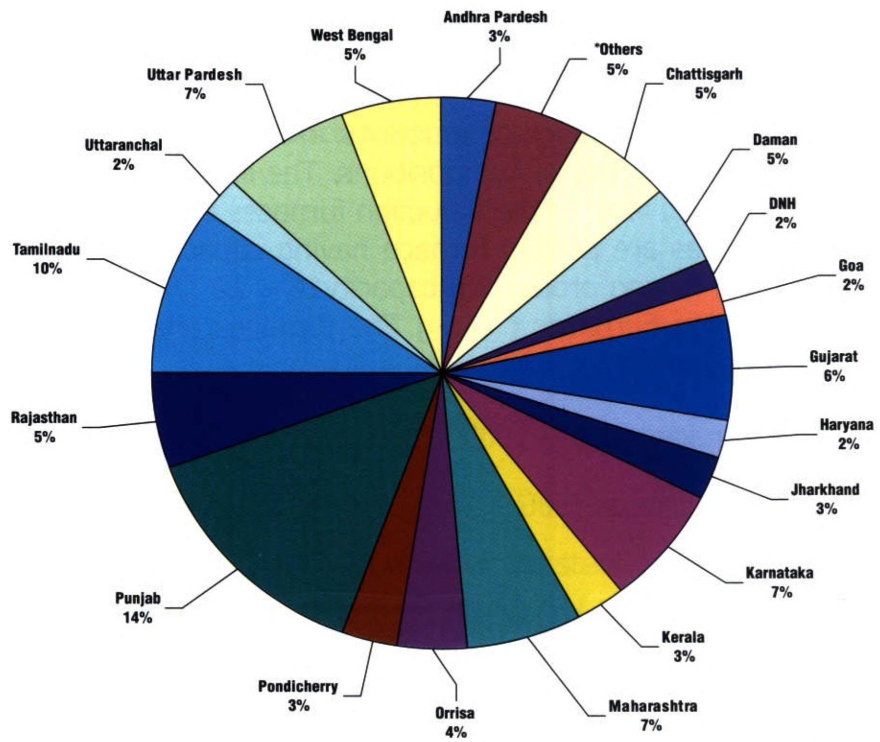
Section 2: Industrial Scenario

2.1 Distribution of IFs in the country

The following charts represent the state wise and region wise distribution of IFs.



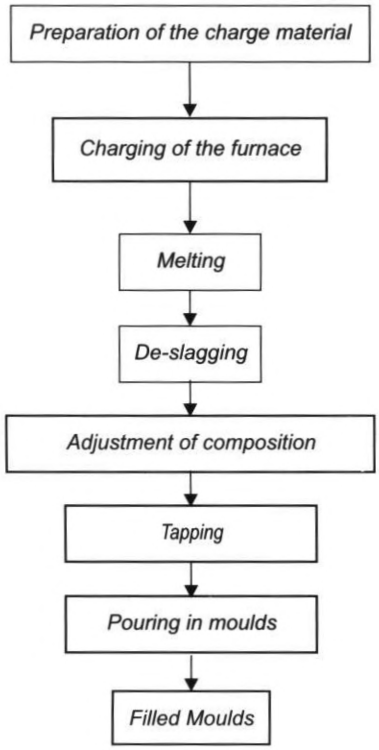
Status of IFs - Regionwise



State wise distribution of IFs

Section 3: Manufacturing Process

A process flow diagram of the steel plant using Induction Furnace is as below:

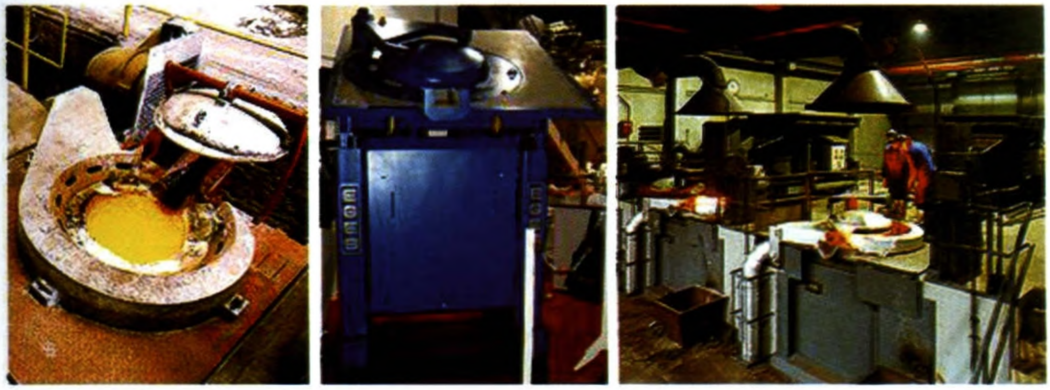


According to the capacity, the furnace is charged by a lifting magnet, bucket skips, a vibrating conveyor or manually. A large number of foundries use induction furnaces for producing relatively small lots in a large variety of compositions. The induction furnaces are producing 500 kg – 22 tonne per charge. Most of the induction furnaces are having capcity 3 T/charge. With the time, the industries are putting furnace having capacity of 10 T, 12 T, 16 T and 22 T/ charge. Bigger units having production capacity16 – 22 T/charge are putting concast machines and Ladle Refining Furnaces (LRF) The furnaces are classified based on their frequency of the current supplied :

- High frequency furnaces (200 – 1000 KHz) supplied from valve generators.
- Medium frequency furnaces (500 – 1000 KHz) supplied from rotary or thyristor convertors.
- Low frequency furnaces (50 Hz) which are fed directly from the mains.

Depending on the installed power density and the melting practice the thermal efficiency can exceed 80%, but usually ranges from 60 to 70%.

The coreless induction furnace can be designed to operate at any frequency from 50 Hz upwards. The induction heating of liquid metal causes a stirring effect. The lower the frequency of the primary current, the more intense is the stirring. Therefore, in a mains frequency furnace working at 50 or 60 Hz, the turbulence is greater than in one operating at higher frequency.



Coreless Induction Furnaces of various sizes

The frequency of operation affects the current penetration. The higher the frequency, the lesser the penetration depth. This affects the minimal charge piece size and the effective furnace size. 50 Hz furnaces are not practicable at capacities below 750kg. At 10 kHz, charge pieces less than 10 mm in diameter can be heated, so furnaces as small as 5 kg capacity can be used. Frequencies are usually limited to 250 to 350 Hz (in the case of variable frequencies), as at higher frequencies metal homogenisation becomes insufficient. Higher frequencies are used in special cases, such as with very small furnaces.

3.1 Inputs to Induction furnace

There are two major inputs to an induction furnace.

- Raw material as steel
- Electrical Energy

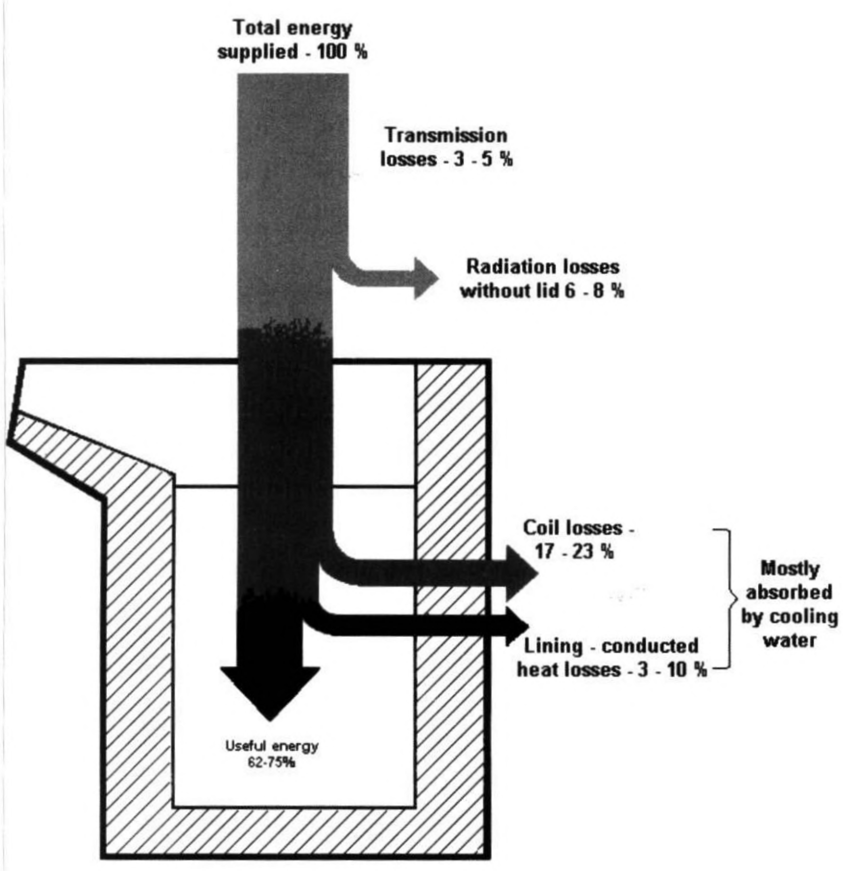
3.1.1 Raw material as steel

The various input materials fed in the furnace are:

- Shredded steel melting scrap – mostly imported from USA.
- Heavy steel melting scrap – mill cut ends or old steel components.
- Light steel melting scrap such as turnings and steel sheets.
- Old cans & coated steel sheet cuttings.
- Pig Iron/Cast Iron
- Direct Reduced Iron
- Ship breaking steel scrap.

3.1.2 Energy

The major source of energy in these plants is electrical energy. The average electricity consumption for making one tonne for liquid metal is 600 – 1000 Kwh. In induction furnaces, 60 % of the cost of production is on electrical energy. In induction furnaces, raw material in various proportions is mixed and put in the furnace. The typical heat losses from a coreless induction furnace are shown below:



3.2 Preparation of raw material and Charging to the furnace

Raw material of various types is mixed into desired proportions to get the final product. Raw material is taken near the furnace floor with the overhead crane. Raw material is either fed manually to the furnace from the top or fed by the overhead crane.

3.3 Melting and Refining

Once the first batch is fed into the furnace, electric current is given and by magnetic induction, the material gets melted. Once the material is melted, second batch of raw material is added into the liquid metal in the furnace. Some alloying elements and lime are added for adjustment of composition and for slag formation. Slag is removed from the top of the furnace.

The Data for 3 Tonne Medium Frequency Induction Furnaces

Sr. No.	General Scrap Used Charge Mix	24 Hr. Working No. of Heats	Lining Life Per Tonne	Power-KWH Consumption
01	80% sponge iron + Mixed Scrap	09	40 heats	820 Units
02	50% sponge iron or more			
	10% CI & mixed scrap	12	50-65 hetas	760 Units
03	30% HMS + 30% sponge &rest mixed scrap + CI	13	60-75 heats	700 Units
04	30% HMS + rest loose mixed scrap	14	90-100 heats	700 units
05	15% LMS bundle + 15% turning bundle + 50% HMS + rest mixed scrap	14-15	100-125 heats	690 Units
06	15% LMS bundle + 30% turning bundle + 40% shredded scrap+ rest mixed scrap	15	100-125 he ats	670 Units
07	15% LMS bundle + 15% turning bundle + 40% shredded scrap + 20% HMS + rest mixed scrap	15-16	100-125 heats	650 hetas
08	15% HMS bundle + 15% turning bundle + 60% shredded scrap + rest mixed scrap	15-16	100-125 heats	650 Units

3.3.1 Refining in Ladle Furnace

The furnaces having batch capacities 16 T-22 T are providing Ladle furnaces for adjustment of the chemistry of the bath.In smaller capacity furnaces, the refining is done itself in induction furnace.

3.4 Tapping/Pouring in Moulds

After a cycle time of 90-120 minutes, the liquid metal is poured into the moulds for the manufacturing of Ingots, Billets etc. Bigger plants have provided continuous casting machines.

Section 4: Sources of Pollution

4.1 Nature of Emissions:

Since no coal or fuel is burned in the induction furnace and no refining procedures are executed, the emissions solely depend on the cleanliness and the composition of the charged material. Two major categories of emissions can be distinguished. The first, and major, category relates to the charge cleanliness, e.g. rust, dirt, foundry sand, paint, oil, galvanised or soldered metal, all of which are elements which give rise to the emission of dust and fumes (organic or metallic). The second category relates to chemical reactions at high temperatures, (e.g. while holding or adjusting the metal composition), which can give rise to metallurgical fume due to oxidation.

Emission – Charging

Emission – Melting

Emission–Melting

Emission–Pouring

Additionally the refractory lining (acidic-SiO_2, neutral-Al_2O_3, or basic-MgO) may add a small amount of dust particles to the emission. It is difficult to obtain average emission data since the charge cleanliness, which is the dominant contributor to emissions, varies from unit to unit to a great extent.

Emission rate from an induction furnace depends upon the charge material which again depends upon the product being made from that furnace. If the product being made is a good quality casting then emissions are of the order of 1 to 2 kg/tonne metal charge but if it is ingot which then emission rates of the order of 10 to 20 kg/tonne metal charge are normal. The highest emission rates occur during charging and at the beginning of the melting cycle. Particle sizes range from 1 – 100 micrometer, with more than 50 % being smaller than 10–20 micrometer. Charging oily scrap or borings in a cold furnace will lead to the presence of organic vapours in the exhaust gases.

Section 5: Field Study Results

NORTH

The cluster of the induction furnace in this region are mainly located in Mandi Gobindgarh, Ludhiana, Jalandhar and Delhi. 25 furnaces were visited in these clusters for the purpose of study. The details of the clusters visited are as under:

Sr. No.	Description	Mandi Gobindgarh/ Ludhiana/ Faridabad	Jalandhar	Delhi
1	No. of Furnaces	73	30	6
2	Capacity (T/heat)	3-10	0.1- 0.5	0.75 – 2
3	Average heat time (hrs)	1.75 – 2.5	1.0	2 – 4
4	Connected Power load (kW)	1500-4000	100-400	750-1250
5	Raw Material	Scrap – 50 -80% Sponge iron: 20 – 50%	Scrap – 55-75% Pig iron–10-15% Fdy returns – 15-30%	SS scrap -100%
6	Product	MS billets	SG Iron casting/malleable casting/ CI casting	SS billets
7	Slag generation	5 – 15%	5–10%	5%
8	Containment system	Swivel canopy hood	Canopy hood	Canopy hood
9	Air Pollution control system	Mechanical shaking bag filter/ pulsejet bag filter/ venturi scrubber/cyclonic scrubber	Cyclone/ Mechanical shaking bag filter	Spray tower/ venturi scrubber

SOUTH

The cluster of the induction furnace in this region are mainly located in Belgaum, Coimbatore and Palakkad. 19 furnaces were visited in these clusters for the purpose of study. The details of the clusters visited are as under:

Sr. No.	Description	Belgaum (Karnataka)	Coimbatore (Tamilnadu)	Palakkad (Kerela)
1	No. of Furnaces	19	20	20
2	Capacity (T/heat)	0.15 – 0.5	0.5–3.0	3 – 6
3	Average heat time (hrs)	0.75 – 1.0	0.5 – 2 .0	2 – 2.5
4	Connected Power load (kW)	125–250	400 -1750	1800-3000
5	Raw Material	Pig iron: 25 – 40% Scrap/foundry returns: 60-75%	Pig iron: 20-40 % Scrap: 60-80%	Sponge iron: 15 – 40 %, Scrap 60-85 %
6	Product	SG Iron casting/CI casting	SG Iron casting/ CI casting	MS billets
7	Containment system	Canopy hood	Canopy hood	Swivel canopy hood
8	Air Pollution control system	No APCD, hood is followed by exhaust stack	Mainly scrubber (spray/packed bed), few units have bag filters	Pulsejet bag filters
9	Slag	2 -4 %	2 – 5 %	5 – 15 %

EAST

The cluster of the induction furnace in this region are mainly located in Durgapur and Hoogly. 11 furnaces were visited in these clusters for the purpose of. The details of the clusters visited are as under:

Sr. No.	Description	Durgapur (West Bengal)	Hoogly (West Bengal)
1	No. of Furnaces	11	14
2	Capacity (T/heat)	6 – 15	3–6
3	Average heat time (hrs)	2 – 3.5	2 – 4
5	Raw Material	Pig iron: 10 – 25% Sponge iron: 70-80% Scrap 5 – 10%	Pig iron: 0–5 % Sponge iron: 25–50% Scrap: 50–75%
6	Product	MS Billets	MS Billets
7	Containment system	Swivel Canopy hood	Swivel Canopy hood
8	Air Pollution control system	Venturi scrubber/ pulse jet bag filter	Scrubber/Pulse Jet bag filter
9	Slag	15–20 %	15 -20 %

WEST

The cluster of the induction furnace in this region are mainly located in Goa, Pune and Thane. 12 furnaces were visited in these clusters for the purpose of study. The details of the clusters visited are as under:

Sr. No.	Description	Goa	Pune/Raigad (Maharashtra)	Thane (Maharashtra)
1	No. of Furnaces	14	8	12
2	Capacity (T/heat)	4–5	5–9	0.3–2
3	Average heat time (hrs)	2 – 2.5	1–3	1–2
4	Connected Power load (kW)	2000–2500	1250–4000	175–750
5	Raw Material	Sponge iron 60 – 70% Scrap: 30-40%	Sponge iron 10 – 20 % Scrap 80-90%	Pig iron: 20-40 % Scrap: 60-80%
6	Product	MS billets	MS Billets	SG Iron casting / CI casting
7	Containment system	Swivel Canopy hood	Swivel canopy hood	Canopy hood
8	Air Pollution control system	Spray scrubber/bag filters	Pulsejet bag filter	Not provided
9	Slag	15 – 18 %	5 -7 %	1– 3 %

Observations (IFs)

Capacity

The capacity of the furnaces engaged in the manufacturing of SG iron casting and CI casting varies from 100 kg to 500 kg per heat. The clusters of these furnaces are mainly located in Jalandhar(Punjab), Belgaum (Karnataka), Coimbatore (Tamilnadu) and Thane (Maharashtra). The capacity of the furnaces engaged in the manufacturing of MS billets varies from 4 ton to 9 ton per heat. Now few units have installed bigger capacity furnaces such as 10 ton per heat to 20 ton per heat with ladle refining furnaces followed by continuous casting plants. The clusters of furnaces manufacturing MS billets are located in Mandi Gobindgarh, Ludhiana (Punjab), Palakkad (Kerela), Durgapur & Hoogly (West Bengal) and Pune/ Raigad (Maharashtra). The capacity of the furnaces engaged in the manufacturing of stainless steel billets varies from 0.75 – 2 Ton/heat. One such cluster of furnaces is located in Delhi.

Heat time

The average heat time of the furnaces engaged in the manufacturing of SG iron casting and CI casting is 1 hr, 2 hrs in case of furnaces manufacturing MS billets and 3 hrs in case of furnaces manufacturing SS billets. The heat time is basically depends upon the availability of power supply. More is the availability of power, lesser is the heat time.

Type and composition of raw material

The composition and nature of the raw material varies from region to region. The furnaces of northern region engaged in the manufacturing of MS ingots are mainly using dirtiest type of scarp including dusty, rusty, painted, galvanized and oily scarp to the tune of 50–80%with 20 – 50% of sponge iron. The power consumption varies from 650 -700 kW per ton of finished product. The smaller capacity furnaces engaged in the manufacturing of castings are using clean scrap to the tune of 70% with remaining 30 % as pig iron and foundry returns. Whereas the furnaces engaged in manufacturing of stainless steel billets are using comparatively clean stainless steel scrap to the tune of 100%.

The furnaces of southern region engaged in the manufacturing of MS ingots are mainly using dirty scarp including dusty, rusty, painted, galvanized and oily scarp to the tune of 60 -85% with 15 -40 % as sponge iron. The smaller capacity furnaces engaged in the manufacturing of castings are mainly using clean scrap to the tune of 60 -80 % with remaining 20–40 % as pig iron.

The furnaces located in Durgarpur of eastern region engaged in the manufacturing of MS ingots are mainly using sponge iron to the extent of 80%, pig iron to the tune of 10-20% with remaining as scrap. Whereas the furnaces located in Hoogly are using sponge iron to the extent of 50% with remaining as scrap with small quantity (around 5%) of pig iron.

The furnaces located in Goa are mainly using sponge iron to the extent of 70% with remaining as scrap. Whereas in Pune/Raigad, the furnaces are mainly using scrap to the tune of 80-90% with small quantity of (10-20%) as sponge iron. The furnaces located in Thane are of smaller capacity engaged in the manufacturing of casting are mainly using clean scrap to the tune of 60-80% with remaining 20-40% as pig iron.

Containment system

Most of the furnaces engaged in the manufacturing of MS billets and SS billets have provided low canopy hoods for the containment of emissions being generated during melting of the raw materials in the furnace. The furnaces located in the North have provided elliptical cut in the furnace hood towards the charging side for the ease of the workers for feeding of the raw material into the furnace. The raw material is being charged into the furnace continuously throughout the cycle time. Generally one furnace has two crucibles. The canopy hoods have been provided with swiveling arrangements so as to serve both the crucibles of the furnace. The swiveling arrangement is being operated manually. The bigger furnaces having capacity more than 8 ton per heat have installed electrically controlled swivel hoods. The gap between hood and furnace was observed to be around 6 inches to 15 inches.

The furnaces located in the southern region engaged in the manufacturing of MS billets have provided pivot arrangement for swiveling the hood for serving both the crucibles on the pouring side of the furnace with underground ducting to the APCD. This arrangement was found to be effective as it provides no hindrance to the movement of overhead crane on the platform.

Swivel arrangement with underground ducting

One of the industries located in western region have installed suction hood which was observed to be quite effective keeping the operational problems during charging of the raw material in view. The photographs of the same is as under.

Suction Hood

The smaller furnaces engaged in the manufacturing of casting have installed canopy hoods with gap between the furnace and the hood as 0.3 -0.5 m as observed in northern region and 2 -3 m in case of southern region. The emissions from these furnaces were found to be on the lower side as these industries are using clean scrap. Most of the industries have not provided with any swiveling arrangement as the furnace is having one crucible only.

Cooling of the Flue Gases

Most of the furnaces in the northern region do not provided any arrangement to bring down the temperature of the flue gases. This may be due to the fact that the APCD are provided at a distance of 150-200 feet away from the furnace. Few of the furnaces have provided cooling duct and water heat exchanger for cooling the flue gases. Where as the industries located in southern region have provided gas coolers to bring down the temperature of the flue gases. The industries in the eastern and western region have mostly provided water heat exchanger to cool down the flue gases.

Air Pollution Control System

The industries have provided mechanical shaking bag filters, pulse jet bag filters, cyclonic scrubbers and venturi scrubbers for the control of suspended particulate emissions. Whereas the smaller furnaces engaged in the manufacture of castings have provided spray scrubber/ mechanical shaking bag filters for the control of particulate emissions. It has been observed that most of the air pollution control devices provided by these industries are locally fabricated with provision of local made ID fans. The suction efficiency of these systems was found to be inadequate because of leakages in the bag filter and poor design of ID fans w.r.t. air handling capacity and pressure. Some of the facts observed are as under:

- Some of the furnaces especially engaged in the manufacturing of castings have provided bag filters, the bags of which are being made from the local available clothes with poor stitching. This would result in poor filtration.
- Most of the industries are not disposing off the dust from the bag filters on regular intervals resulting in excessive pressure drop across the bag filter leading to poor suction efficiency.
- No instruments like manometers were provided to check the pressure drop across the bag filter so as to identify the leakages/ chockage of the bag filters.
- No maintenance schedules for checking the bag filters/scrubbers, ID fans are being followed.
- Most of the industries do not have any record regarding their dust generation from the air pollution control systems. This may due to the fact that either they are not operating the system regularly or not having dedicated man power to operate and maintain the system.
- Most of the smaller furnaces engaged in the manufacturing of castings located in the southern region have not provided with any air pollution control systems. The furnaces were provided with only high canopy hoods followed by an exhaust chimney to vent out the flue gases.

Emissions from the sheds because of poor efficiency of APCDs

- The emissions from the smaller capacity furnaces (100 -500 kg per heat) manufacturing castings and stainless steel billets were observed to be on the lesser side as the raw materials being used by theses industries are comparatively clean.
- One industry namely in the southern region have provided on-line PM monitoring kit in the outlet chimney to monitor the PM levels. The cost of the kit as informed by the industry is Rs. 3.5 lacs.

Emissions from the sheds because of poor efficiency of APCDs

Section 6: Emission Monitoring Results

The emission monitoring includes particle size distribution, performance evaluation of the air pollution control technology, work zone monitoring and ambient air monitoring. The results of the monitoring are tabulate as under:

Particle Size Distribution

Particle Size	North		South	East	West
	Unit A	Unit B	Unit C	Unit D	Unit E
Product	MS billets	SS billets	MS billets	MS billets	MS billets
Raw Material Composition	Scrap: 80-90% Sponge Iron: 10-20 %	SS Scrap: 100%	Scrap 85% Sponge iron 15%	Pig iron 20% Sponge Iron 70% Scrap 10%	Sponge Iron 10-20% Scrap 80–90%
0-2	4.13%	35.00 %	0	41.60 %	5.80 %
2-10	17.57%	32.21%	6.54 %	28.30 %	19.20 %
10-20	10.70%	9.55 %	9.91 %	7.60 %	21.00 %
20-30	5.00%	7.40 %	9.67 %	4.80 %	11.40 %
30-40	6.60%	4.30 %	11.00 %	3.80 %	17.60 %
40 & above	56.00%	11.54 %	62.93 %	13.90 %	25.00 %

- It has been observed that particle size percentage varies with respect to the variation in the composition of the raw material from region to region.
- The particle size percentage in case of Unit B is totally different as the industry is using 100% stainless steel scrap for the manufacture of SS billets.
- It has been observed in case of Unit D metal cast that more is the percentage of sponge iron used, more is the percentage of fine particles whereas it is found to be otherwise in case of industries using less percentage of sponge iron.

Performance monitoring of the pollution control system

Sl.	Description	North		South	East	West
		Unit A	Unit B	Unit C	Unit D	Unit E
1	Capacity (Ton/heat)	5	2	6	7 & 5	9
2	Raw Material Composition	Scrap: 60-70 % Sponge Iron: 30-40 %	SS Scrap: 100%	Scrap 85% Sponge iron 15%	Pig iron 20% Sponge Iron 70% Scrap 10%	Sponge Iron 10-20% Scrap 80–90%
3	Product	MS billets	SS billets	MS billets	MS billets	MS billets
4	Design flue gas volume (Nm^3/hr)	8800	4944	16250	-	-
5	Technology for pollution control	Venturi Scrubber	Spray tower	Gas Cooler followed by Pulse jet bag filter	Venturi Scrubber	Pulse jet bag filter

Monitoring Results

Sl. No.	Description	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1	Flue gas volume Nm^3/hr	8735	8081	6492	6304	16279	19738	9818	9683	16841	20206
2	Temperature (^0C)	138	43	47.4	41	60	49	56	45	138	62
3	Velocity (m/sec)	14.90	11.55	9.86	10.25	18.6	2.68	22.8	9.83	16.78	3.57
4	PM (mg/Nm^3	1307	112	185	92	1 31.2	45.9	153	60	1874	133
5	PM (kg/tone)	4.56		1.2		0.71		0.42		10.52	
6	NO_x (mg/Nm^3)	-	-	-	-	47	-	-	-	-	-
7	VOC as Total hydrocarbons	ND	-	-	-	ND	-	-	-	-	-

8	**Work Zone SPM (8 hourly sample) (mg/m^3)**					
	APCD Working APCD Not Working	3.33 (12 hrs) -	2.40 4.58	0.0325 0.0726	1.27 3.37	3.90 4.72

Ambient Air Quality Monitoring Of Unit A

Sampling Stations	APCD ON SPM ($\mu g/m^3$) 1st day	APCD OFF SPM ($\mu g/m^3$) 2nd day
	Duration or Sample -5 hrs (13.00-18.00 hrs)	
Station 1 (roof of labour room)	412	464
Station 2 (Near the scrap storage area)	688	1442
Station 3 (Roof of hazardous waste storage room)	340	380

Ambient Air Quality Monitoring Of Unit C

Sampling Stations	APCD ON (1st day)			APCD OFF (2nd day)		
	RSPM ($\mu g/m^3$)	NRSPM ($\mu g/m^3$)	TOTAL SPM ($\mu g/m^3$)	RSPM ($\mu g/m^3$)	NRSPM ($\mu g/m^3$)	TOTAL SPM ($\mu g/m^3$)
	Duration of sample -8 hrs (12.40-20.40 hrs)			Duration of sample -4 hrs (11.20-15.20 hrs)		
Station 1 (Western side of Induction Furnace No. 2 (42 m from furnace no. 2)	100.37	11.85	112.220	2753.030	759.09	3512.12
Station 2 (Eastern side of Induction Furnace No. 1 (142 m from furnace no. 1)	94.259	10.740	104.999	759.689	220.930	980.619

Ambient Air Quality Monitoring Of Unit C

Sampling Stations	APCD ON (1st day)		APCD OFF (2nd day)	
	SO_2 ($\mu g/m^3$)	NO_x ($\mu g/m^3$)	SO_2 ($\mu g/m^3$)	NO_x ($\mu g/m^3$)
			Duration of sample -4 hrs (11.20-15.20 hrs)	
STATION 1 (Western side of Induction Furnace No. 2 (42 m from furnace no. 2) Sample 1 (Duration 4 hrs – 12.40 to 16.40 hrs)	0.0606	0.0905	0.5097	0.6339
Sample 2 (Duration 4 hrs – 16.40 to 20.40 hrs)	0.0303	0.0603		
STATION 2 (Eastern side of Induction Furnace No. 1 (142 m from furnace no.1) Sample1 (Duration 4 hrs – 12.40 to 16.40 hrs)	0.0303	0.0603	0.2018	0.2415
Sample2 (Duration 4 hrs – 16.40 to 20.40 hrs)	0.0303	0.0301		

Ambient Air Quality Monitoring Of Unit E

Sampling Stations	APCD ON	
	RSPM (μg/m³)	SPM (μg/m³)
	Duration of sample 8 hrs (15.00 -23.00 hrs)	
Station 1 (Near Scrap Yard)	151	221
Station 2 (Near Office Terrace)	93	289
Station 3 (Near Gas Plant)	253	534

Observations on the monitoring results–IFs

Unit A

- The performance evaluation of the technology was carried out by simultaneously putting two samplers before APCD and after APCD. The PM concentration before APCD and after APCD was found to be 1307 mg/Nm³ and 112 mg/Nm³ respectively with efficiency of venturi scrubber as around 92%.
- No VOC was detected at the inlet of APCD.
- The SPM levels in the work zone during APCD in operation was found to be 3.33 mg/Nm³ against the permissible limit of exposure (time weighted average concentration of 8 hrs) of 10 mg/Nm³ as indicated in the Factories Act, 1942. The sampler during work zone monitoring was placed at a height of 1.8 m from the floor and at a distance of 5 m from the furnace.
- The SPM concentration in the ambient air during APCD in off condition was found to be 1442 μg/m³ at station 2 against 688 microgram/m³ during APCD in operation. The SPM concentration at this station was found to be higher in comparison to other station because of the direction of the wind was towards this station. During ambient air monitoring, three samplers were placed at an angle of 120^0 with each other at a height of around 10 feet from the ground.

Unit B

- The PM concentration before APCD and after APCD was found to be 185 mg/Nm³ and 92 mg/Nm³ respectively with efficiency of spray scrubber as around 50%.
- The SPM levels in the work zone during APCD in off condition was found to be 4.58 mg/m³ and 2.40 mg/m³ during APCD in on condition against the permissible limit of exposure (time weighted average concentration of 8 hrs) of 10 mg/Nm³ as indicated in the Factories Act, 1942.

Unit C

- The PM concentration at the inlet of the APCD was found to be 245.9 mg/Nm³ against 1307 mg/Nm³ found in case of Unit A. The PM concentration was found to be very low and the factors responsible for the same are as:

- ✓ Longer process heat time (3.5 hrs) against heat time of 2 hrs in case of Unit A
- ✓ The industry was using comparatively clean and shredded scrap in comparison to Unit A.
- ✓ The air handling capacity of the APCD in case of Unit C for their 6T furnace was found to be 16,250 Nm^3/hr in comparison to 8800 Nm^3 /hr in case of Unit A for their 5T furnace. The flue gas volume was found to be 95% higher than Unit A against 20% higher capacity of the furnace. It indicates that a lot of dilution is taking place.

- The efficiency of the pulsejet bag filter was found to be 47% only against the desired efficiency of more than 95%. This may be due to the non maintenance of the bag filter.
- No VOC was detected at the inlet of the APCD
- The concentration of NOX at the inlet of APCD was found to be 47 mg/Nm^3.
- The SPM levels in the work zone during APCD in operation was found to be 0.0325 mg/m^3 and 0.0726 mg/m^3 during APCD in off condition against the permissible limit of exposure (time weighted average concentration of 8 hrs) of 10 mg/Nm^3 as indicated in the Factories Act, 1942. The sampler during work zone monitoring was placed at a height of 1.6 m from the floor and at a distance of 3 m from the furnace.
- The SPM concentration in the ambient air during APCD in off condition was found to be 3512.12 microgram/m^3 against 112.22 microgram/m^3 during APCD in operation. The SPM levels of 3512.12 microgram/m^3 was found to be on the higher side in comparison to work zone SPM levels of 72.6 microgram/m^3.
- The levels of SO_2 and NOx were also monitored in the ambient air. The concentration of SO_2 and NOx was found to be less than 1 microgram/m^3 during APCD in off condition.

Unit D

- The PM concentration before APCD and after APCD was found to be 153 mg/Nm^3 and 60 mg/Nm^3 respectively with efficiency of venturi scrubber as around 40% against the desired efficiency of more than 90%. The PM concentration of 153 mg/Nm^3 before APCD was found to be very low in comparison to the PM concentration of 1307-1874 mg/Nm^3 observed in case of Unit A & E
- The SPM levels in the work zone during APCD in off condition was found to be 3.37 mg/m^3 and 1.27 mg/m^3 during APCD in on condition against the permissible limit of exposure (time weighted average concentration of 8 hrs) of 10 mg/Nm^3 as indicated in the Factories Act, 1942.

Unit E

- The PM concentration before APCD and after APCD was found to be 1874 mg/Nm^3 and 133 mg/Nm^3 respectively with efficiency of pulse jet bag filter as 93%.
- The SPM levels in the work zone during APCD in off condition was found to be 4.72 mg/m^3 and 3.90 mg/m^3 during APCD in on condition against the permissible limit of exposure (time weighted average concentration of 8 hrs) of 10 mg/Nm^3 as indicated in the Factories Act, 1942.
- The SPM concentration in the ambient air during APCD in operation was found to be in the range of 221-534 µg/m^3.

Section 7: Pollution Control Technologies

The induction furnaces are basically of two types i.e. smaller furnaces upto capacity of 1T/ heat and bigger furnaces having capacity more than 1T/heat to 20T/heat. The clusters of the smaller furnaces are located in Jalandhar (Punjab), Belgaum (Karnataka), Coimbatore (Tamilnadu) etc. The smaller furnaces are basically engaged in the manufacture of SG Iron, Malleable & CI Castings. These furnaces are using clean scrap (MS & CI) with small quantity of pig iron. The dust emissions from these furnaces were observed to be negligible as compared to the dust emissions being observed in the furnaces manufacturing MS billets. Most of the smaller furnaces located in the northern region have installed low canopy hoods for the containment of dust emissions followed by bag filters. Whereas most of the furnaces located in southern and eastern regions have installed high canopy hoods followed by an exhaust chimney to vent out the flue gases. The suction efficiency of these systems was found to be poor as the air pollution control systems in this category of furnaces are manufactured and supplied by the local fabricators.

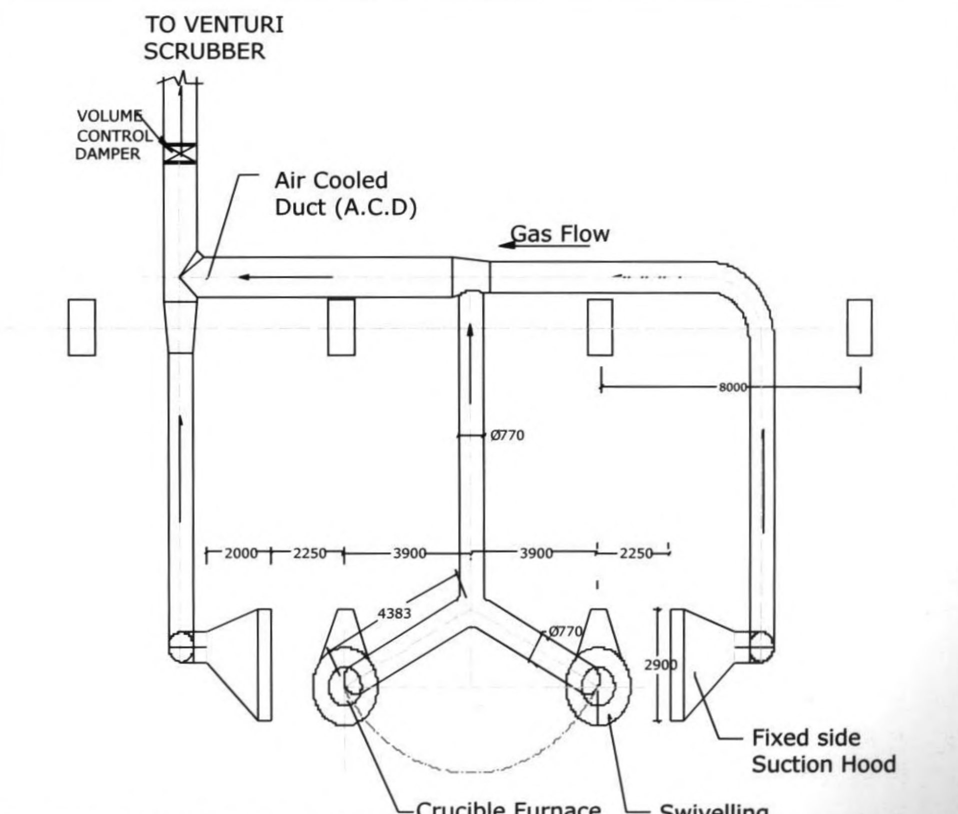
The furnaces manufacturing SS billets are using comparatively clean SS scrap to the tune of 100%. The PM levels at the inlet as well as the outlet of air pollution control system was monitored and found to be 185 mg/Nm^3 and 92 mg/Nm^3 respectively with efficiency of spray scrubber as 50%. The dust emissions from these furnaces was observed to be on the lower side as compared to the furnaces manufacturing MS billets because of the comparatively clean nature of the scrap.

The capacity of the induction furnaces manufacturing MS billets varies from 3 T/heat to 20 T/heat. The clusters of these furnaces are located in Mandigobindgarh / Ludhiana (Punjab), Palakkad (Kerela), Durgapur (West Bengal) and Raigad (Maharashtra). These furnaces are using dirty scrap including dusty, rusty, painted, galvanized and oily scrap with sponge iron. The furnaces located in northern and southern regions are using sponge iron to the extent of 50% whereas the furnaces of eastern region are using sponge iron to the extent of 80% with remaining as scrap. The dust emissions from the furnaces using more quantity of scrap (80-90%) were observed to be high as compared to the furnaces using more quantity of sponge iron (70-80%).

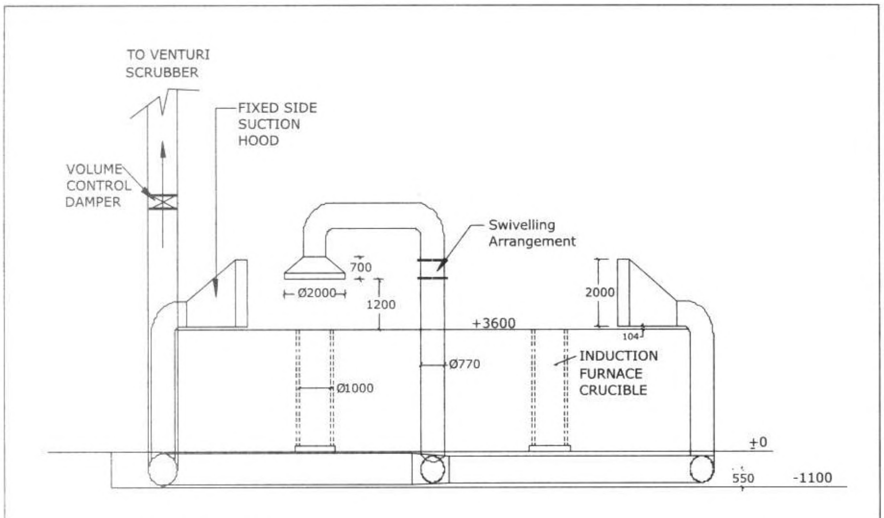
7.1 Containment system

It has been observed that most of the induction furnaces have provided low canopy hoods for the containment of dust emissions being generated from the furnaces during melting of the raw materials. The raw materials i.e. scrap and sponge iron are being charged into the furnace through out the cycle time of around 2 hrs. In low canopy hoods, the distance between the furnace and the hood is being maintained as 0.4- 0.8 m. It has been observed that most of the furnaces are not able to keep the hood on the furnace because of the operating problems faced during poking of the charge materials into the furnace and the irregular size & shape of the scrap. Moreover the suction of the emissions into the hood was also affected by the man cooler installed on the charging platform and the cross currents. Although the man cooler is being provided for the comfort of the workers because of the intense heat on the platform but the workers are using this high RPM fan to throw away the dust emissions / fumes being generated from the furnace. Moreover it has been observed that number of industries is upgrading their furnace capacity without upgrading the capacity of the pollution control device. This would lead to poor suction efficiency of the air pollution control system with high dust levels in the work zone environment. The dust coming out from the sheds would further deteriorate the quality of the ambient air.

The containment system shown in the figure below was found effective in containing the emissions in some of the units.



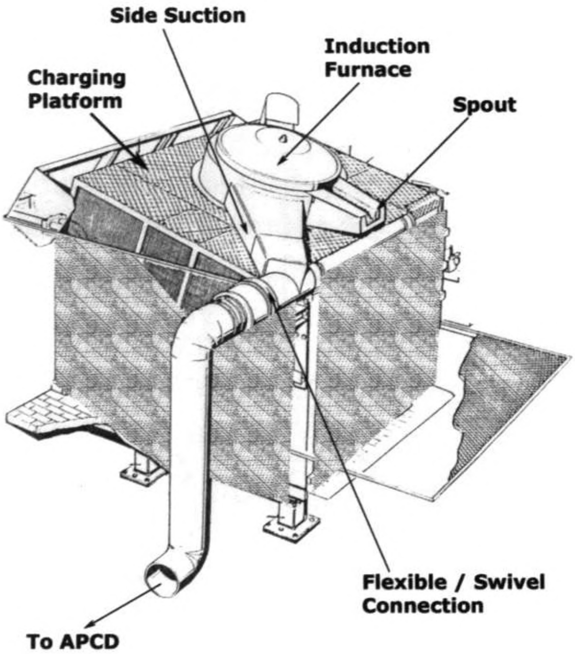
PLAN (CONTAINMENT SYSTEM) Ø1000



ELEVATION
(CONTAINMENT SYSTEM)

In the above said containment system, the hood is placed at a height of 1.2 m above the furnace so that the workers will not face any problem during poking of the raw materials and irregular size & shape of the scrap. Two side hoods are proposed to take care of the cross currents. The pivot arrangement for swiveling the hood is proposed on the pouring side of the furnace with underground ducting to air pollution control device. This type of arrangement will not provide any obstruction to the movement of overhead crane. The proposed containment system would increase the volumetric flow rate requirements.

Alternatively for the furnaces which are using clean scrap and keeping the lid of the furnace closed during melting of the raw materials in the furnace, annular ring shall be provided



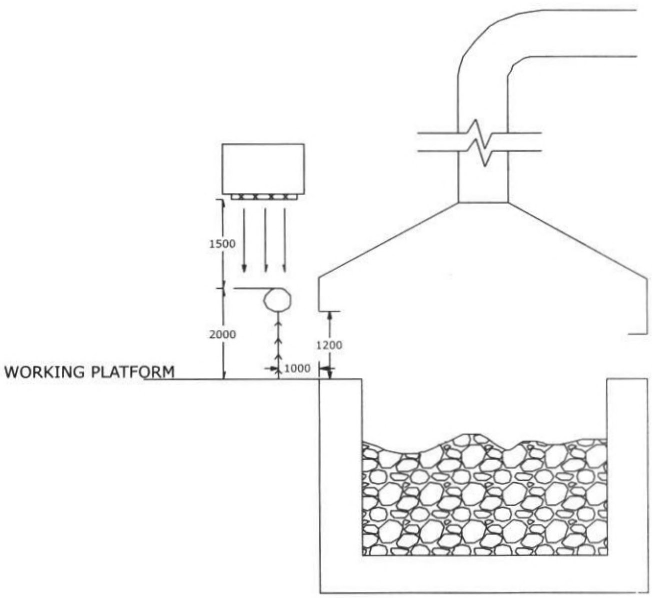
Containment System

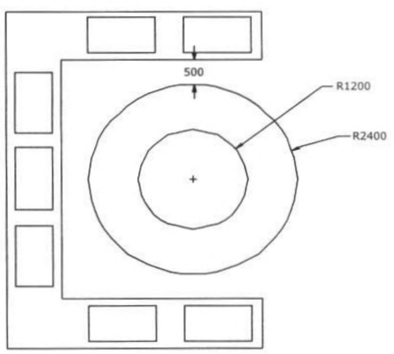
along the circumference of the furnace with side suction so as to contain the emissions. The figure showing the same is as under:

7.2 Air Curtain

Most of the furnaces are using man-coolers installed on the charging platform to provide comfort to the workers working near the furnace area because of intense heat. But it has been observed that the workers are directing these man-coolers towards the furnaces to throw away the high temperature dust emissions being generated during furnace operation. This would result in poor suction efficiency of the air pollution control device with high dust level in the work zone environment as well as in the ambient air. To counter this effect, some of the industries have installed APCDs of higher air handling capacities with higher energy consumption.

An air curtain is recommended to be provided to provide the cool air to the workers without interfering with the operation of APCD. The schematic arrangement of the air curtain is shown as under:





PLAN

7.3 Air Pollution Control Technology

The induction furnaces have either installed bag filters (mechanical shakers/pulse jet) or scrubbers (cyclonic/venturi) for the control of Particulate Matter (PM). These furnaces are using dirty scrap including oily, painted and galvanized scrap with sponge iron. As already mentioned, the hoods are placed at a distance of 0.4–0.8 m from the furnace. The dilution of air because of this gap between the furnace and the hood would result in temperature drop of the flue gases. As the pollution control devices are installed at a distance of 50–70 m from the furnace, the temperature of the flue gases falls below the dew point and the condensation will take place. Moreover care has to be taken with respect to the presence of oil in the scrap, as oily vapour could condense on the filter cloth, where it could block the pores and make the removal of adhering dust impossible. As a result the bag filter got chocked resulting in excessive pressure drop across the bag filter. This leads to poor suction efficiency and increased in the SPM levels of the work zone and ambient air environment. Hence bag filters does not seem to be technically feasible.

During emission monitoring, the maximum concentration of PM before air pollution control device was observed to be 1874 mg/Nm^3. Keeping the sticky and corrosive nature of the dust in view, it is proposed that venturi scrubber is the only technically feasible solution for the control of PM from the induction furnaces especially for the those which are using oily and galvanized scrap. The PM levels of 150 mg/Nm^3 can be achieved economically with venturi scrubber having performance efficiency of 92%. This efficiency can be achieved with a throat velocity of 250 fps with pressure drop as around 20 inch. The collection efficiency of the venturi scrubber is 100% for the particles above 4 micron, 97% between 2- 4 micron, 80% between 1 -2 micron and 65% below 1 micron. In the case of venturi scrubbers, ph of scrubbing liquid should be maintained up to 8.5 by adding any alkali like caustic soda or soda ash etc. Then the turbidity, total suspended solids (TSS), chemical oxygen demand (COD), iron etc. will be within the limits.

However the bag filter technology can also be applied for the control of suspended particulate matter for the induction furnaces using non oily and non galvanized scrap. The bag filter shall be provided in compartments preferably in five compartments with 25% extra capacity so as to attend the necessary repairs/replacements without interrupting the furnace operation.

7.4 Total cost of the APCD

Type of APCD	Capital cost (Lacs)	O & M cost/annum (Lacs)	Total O & M cost/annum considering life of equipment as 7 years (Lacs)
Venturi Scrubber	20	10	13
Bag Filter	50	12	19

The annual turnover of 5 T/heat IF manufacturing MS ingots was reported to be around 50 crores. The environmental cost works out as 0.4% of the annual turnover much below the limit of 3% as per the requirement of National Enviornment Policy 2006.

7.5 Treatment of Slag

Like dust generation, slag forming is an indispensable part of the steel making process and can not be prevented or controlled totally. The slag amounts to about 250-750 kg/ton of steel produced depending upon the raw material to be used. More is the quantity of sponge iron used, more is the generation of slag. Ferrous slag components are separated by magnetic precipitators. The slag has to be crushed, screened and sized for use.

Depending on the actual composition, the slag can be used for road construction and for making concrete blocks after grinding as a replacement of coarse aggregates. The deciding factors with respect to these uses are environmental acceptability and structural suitability.

CHAPTER IV: RECOMMENDED STANDARDS

Minimal National Standards for Electric Arc & Induction Furnaces

Based on the findings of the study, following standards have been proposed:

Industry	Parameter	Emission Standard (mg/ Nm^3)		Load/ Mass standard Kg/ tonne of steel melt	
		Existing Unit	New Unit	Existing Unit	New Unit
Electric Arc & Induction Furnaces	Particulate Matter	100	50	0.4	0.2

Note: the unit shall channelize their emission through a stack/ chimney of atleast 30 (thirty) metre above ground level or atleast three metre above top of shed/ building whichever is more.

Guidelines:

Fugitive Emission Control: The particulate matter should not exceed 2000µg/m^3 at a distance of 3-10 m from major dust generating source from electric arc and induction furnaces.

Solid Waste Management:

Dust from bag filter if found hazardous it should be handled as per Hazardous Waste management Rules (1989) as amended till date. Or it may be recycled in the process by making pellets, etc.

Slag may be crushed, screened and sized for use in road construction or making concrete block depending on composition.

The above proposed standards have been approved by the Peer & Core Committee and thereafter by the Central Board. The approved standards have been forwarded to Ministry of Environment & Forests for consideration for Notification.

CHAPTER V: GOOD PRACTICES

5.1 ELECTRIC ARC FURNACES

5.1.1 Ultra High Power Operation (UHP)

The efforts to reduce tap –to- tap times led to the installation of more powerful furnace transformers. UHP operation of arc furnaces can reduce the melting time by about 50% and hence improve the specific energy consumption. Keeping the refining and other furnace operating time unchanged, it may be possible to increase the productivity by at least 30% in terms of the number of heats reduce per day.

UHP transformers have been adopted and EAF transformer rating has been raised to around 700 KVA/ton to 1000 KVA/ton, so as to provide for faster melting rates and reduced tap- to- times. UHP operation may also result in reduced specific electrode consumption. Increasing the size of the transformer provides more electric energy to the furnace, allowing faster heats that result in more dust to the collection system. The following table shows relation among capacity of the furnace viz a viz capacity of the transformer required for UHP operation.

Nominal capacity of furnace (Ton)	Capacity of transformer (MVA)
20	15
30	22
50	30
60	35
70	40
80	45
100	50
120	60
150	70
170	80
200	100
400	150

Source: Cast Product Hand Book, 4th Edition, Japan Cast Product Association

5.1.2 Water Cooled Side walls and Roofs

Currently there is a trend in the design and management of electric furnace which leads to the use of high power transformers. This trend may be linked to the necessity of reducing melting and refining time as much as possible in order to obtain high yield rates. However, the use of high power implies a significant increase in furnace refractory consumption. In a bid to reduce refractory wear, it is important to limit the rise in temperature of the roof and wall of the electric arc furnace.

Water cooled panels are installed to replace refractory material in the furnace. Water cooled panel for wall lining and water cooled roof can reduce the basic refractory consumption to a great extent because more than 75% of the side wall and more than 80% of roof area are replaced by water cooled system. Apart from the hearth and the wall adjacent to the slag line where refractory bricks will continue to be used, water cooled panels can replace the conventional refractories in all other areas.

The furnace walls and roofs have been lined with water panels, providing the opportunity to save refractory material and also to reuse waste heat by the application of measures for energy recovery. The economic viability of recovery of energy has to be checked on a plant to plant basis. An additional energy consumption by water cooled side walls and roof of about 10-20 kWh/t is assumed to be compensated by advantages in the field of plant availability and maintenance. These water cooled panels allow larger melts due to the increase available area for the charge. A bag house that is performing efficiently may be over loaded by increased dust load from each heat.

5.1.3 Oxy-fuel burners and Oxygen lancing:

The conservation of electrical energy to the EAF has been a matter of primary importance and has been achieved by substituting a part of the electrical energy with oxygen lancing and oxy-fuel burners. This, in turn, increases productivity because of reduction in tap to tap time.

The position of electrodes in the electric arc furnace leads to hot and cold spots around the circumference of the furnace, leading to increased power consumption. In order to overcome the cold spot problem and at the same time to increase the rate of melting, so as to reduce the tap to tap time, oxy-fuel burners are used. The use of excess oxygen(10-20 %) results in inflammable materials charged with the scrap being combusted inside the furnace rather than in the exhaust system. Operationally between 3-10 ltrs of kerosene or fuel oil per ton of steel are used together with 6-20 cubic meter of oxygen. Upto 50 kWh of electrical energy can be supplied by the use of oxy-fuel burners to increase the melting rate by about 15%.

Automatic lance manipulators are also being used for injection of oxygen and carbon fines, required for foamy slag practice for effective power inputs and minimizing heat losses. Every cubic meter of oxygen input is equivalent to a saving of about 4 kWh/ton liquid steel. Usually, additional energy input by oxy-fuel burners and oxygen lancing results in a decrease of total energy input required. Adding an oxy burner in the electric arc furnace increases the heat. This additional energy reduces the melt time, causing an increase in grain loading over a shorter period of time.

5.1.4 Electrode Controllers

Effective automatic electrode control is one of the most important factor in efficient arc furnace operation since the energy consumption, melting time, electrode and refractory consumption as well as the load factor presented to the supply system depends largely on the speed and precision with which the electrodes are controlled and positioned in the furnace.

Developments in solid state technology has helped to evolve thyristor controls for electrode movement. Energy requirement for a thyristor controller is bare minimum and it has also been reported that the response of thyristor controllers is better as compare to that of other controllers.

5.1.5 Waste Heat Recovery

Pre-heating of scrap is a practice to tap the waste heat in the exhaust gases. The temperature to which the scrap can heated depends on the duration of the heat and the heating arrangements. Scrap pre-heated to a temperature of 300-600^{0}C leads to reduction in tap to tap time by 8-10 minutes and a saving of 30-40 kWh/t in electrical energy. The cost of equipment required for scrap pre heating of capacity 10-15 ton will be about 70-80 lacs. This would lead to reduction in dust emissions in the flue gas. However, this option needs to be evaluated thoroughly with respect to economic viability.

During the project studies, it was observed that one of the units at Maharashtra had explored the viability of heating the scrap through waste gases. The industry achieved reduction in energy consumption by 25-30 kWh per ton of steel produced with a capital investment of Rs. 50.0 lacs whose present value is around Rs. 1.5 crores. Presently the industry is not practicing the pre heating of scrap because of following practical problems:

- The system was found to be only viable for units using 100% shredded scrap as other raw materials such as turning & boring and sponge iron gets partially melted in the pre-heating chamber. This would result in chocking of the system. Whereas only small rise in temperature was found in heavy scrap.
- Difficulty in taking out the pre-heated raw material from the pre-heating chamber thereby resulting in production loss.
- Pressure drop across the pre heating chamber (around 100 mm) leads to increase in energy consumption of the ID fan.
- Formation of organic emissions and dioxins

Excessive pressure drop across the pre-heating chamber thereby requiring more energy to suck the emissions from the furnace.

5.1.6 Eccentric Bottom Tapping (EBT)

The practice of EBT is widely adopted now a days, as it makes possible slag free tapping with tapping angle of about 12^0 against 12^0-42^0 in non EBT furnaces. It also allows cost savings for the lowering of refractory material needed, reduction in tap to tap time, reduction of heat losses and shorter power cables. Bottom tapping is beneficial for maintaining low nitrogen levels because tapping is fast and a tight tap stream is maintained. Usually most of the new electric arc furnaces are equipped with EBT systems.

5.1.7 Automation

Computer control in electric arc furnace plants has become necessary within recent years, as the high throughputs require efficient control system to manage the material and data flows arising in the raw material selection, EAF, ladle furnace and continuous casters. Efficient control systems permit an increase in productivity, a reduction in energy consumption and also a decrease in dust emissions.

5.1.8 Ladle or Secondary metallurgy

Some production steps need not to be carried out in the EAF itself and can be performed more efficiently in other vessels (like desulphurising, alloying, temperature and chemistry homogenization). These tasks have been shifted from the EAF to ladle furnaces. The reported benefits of this development are energy savings (net savings of 10-30 kWh/ton), a reduction of tap to tap times of about 5-20 minutes, increasing the productivity, a better control of temperature of the heat delivered to the caster, a possible reduction of electrode consumption (up to 0.1-0.74 kg/t), alloy savings and a decrease of the emissions from the EAF itself. A possible drawback of using ladle furnaces with respect to air pollution control is the increase in the number of emission sources and requiring higher expenditure for air pollution control equipment.

5.1.9 D.C. Arc Furnaces

The DC arc furnace is similar to conventional AC arc furnace in metallurgical operation with better stirring of liquid bath. A major problem faced by AC arc furnace operators is that of "flicker", which is dependent on the strength of the local power grid. Consequently in areas with low or insufficient grid strength, it becomes necessary to install costly flicker compensation equipment to mitigate the harmful effects of EAF operation on the utility grid. Essar steel set up India's first DC arc furnace.

The DC arc furnace has single top graphite electrode instead of three graphite electrodes. Roof is similar to conventional water cooled/refractory roof with single hole for electrode entry. In AC arc furnace, there are 8-10 operations of circuit breaker during melting of one heat. The circuit breaker in AC furnace is tripped during short circuiting, charge collapse, tap changing, charging and electrode addition. Whereas in DC arc furnace, circuit breaker is not switched off, instead thyristors are switched off thereby minimizing costly maintenance of high voltage circuit breaker. Bottom electrode is the major component of DC arc furnace through which the liquid bath is continuously stirred. This leads to homogenization of chemistry and temperature of liquid metal bath. In AC arc furnace, temperature distribution on the surface is not uniform due to flaring of arcs and hence cold spots form in the furnace. DC furnace is more effective in terms of bath stirring enabling faster scrap melting with no risk of un-melted scrap and flow of current causes better stirring of liquid metal. If we compare the AC arc furnaces with DC arc furnaces, following advantages of DC arc furnaces would be observed:

- Decrease in tap to tap time by 5%
- Decrease in electrical energy consumption by 5-7%

- Temperature uniformity due to better stirring
- Low electrode consumption (reduction by 50% e.g. in a 30 ton DC arc furnace, electrode consumption is 1.8 kg/t against 3.5-4.5 kg /t in AC arc furance)
- Considerable reduction in Flicker (by over 50%)
- One electrode arranged in the centre prevents any local refractory lining over heating
- Reduced maintenance of various parts like electrode holder, electrode drives, high voltage switchgear etc.
- Less expenditure on pollution control system because of lesser generation of emissions.
- Improved environmental conditions due to less noise during furnace melting and working.

5.1.10 Single Electrode DC Ladle Refining Furnace

The experience on single electrode DC ladle refining furnace has been quite successful. The power consumption for a 7MT furnace was found to be 80 kWh/t with electrode consumption of 0.25 kg/t. The processing time varied from 35-45 minutes.

It was not possible to make smaller capacity LRF with AC power because of 3 electrodes. It is now possible to go for very small capacity LRF such as 4-5 MT with single electrode. Argon consumption of DC LRF was same as AC LRF i.e. 1-2 Nm^3 argon/hr.

5. 1.11 Energy Efficiency in Steel Industry

Steel foundry industry is an energy intensive sector. Adequate energy management can save about 10% of electrical energy consumption. The energy consumption per ton of metal can be brought down by:

Scrap preparation:

The bulk density and the scrap size have a close relation with the specific energy consumption. It is quite important to reduce the number of back charges per heat, as it results in less frequent opening of furnace roof, which reduces the heat losses. Each reopening of the furnace is expected to increase energy consumption (Refer Table1).

Table–1 Energy Loss in Relation to the Duration of Roof Opening

Minutes	kWh/ton
0	0
2	2.5
4	4.8
6	7
8	9.2
10	11.5
12	13.8

Therefore, it is worthwhile to install presses to reduce the volume of scrap to be charged with the objective of reducing the charging time. It also reduces melting time by 5-15 minutes which leads to energy savings of 7-10 kWh/ton against the energy consumption of 2-3 kWh/ton required for pressing the light scrap (Table 2).

Reductions	Percentage
Charging time	30 %
Melting time	5 %
Electric power consumption	10 %
Refractory consumption	1 kg/ton
Electrode consumption	0.3 kg/ton
Increase in Yield	4%

Scrap Segregation:

Charging the furnace without segregating the charge according to composition results in wide variations in opening carbon. Due to high opening carbon, the oxidation period increases which in turn results in higher power on to – tap time with higher specific energy consumption. Hence the scrap can be segregated as per the carbon content and charging can be done accordingly as per the requirement.

Oxygen Lancing

In steel making practice, oxygen plays a predominant role for increasing productivity as well as decreasing over all energy consumption. The use of oxygen during the melting stage results in reduction in melt down time because of the exothermic reaction of oxygen with iron and with combustible element present in the scrap. It results in reduction in tap to tap time and thus saving in specific electrical energy consumption due to reduction in fixed losses in the furnace. Besides energy savings, uniform melting during each charge can be achieved.

It has been reported that the use of one cubic meter of oxygen per ton of metal will reduce the specific energy consumption by 4.4 kWh. It has been observed that the economic limits for oxygen uses is 14-20 cubic meter per ton of metal. Higher values of oxygen injection results in lower metallic yield. Proper oxygen lancing can reduce power requirement in melting upto 75 kWh/ton.

Temperature Control

Temperature control of the liquid metal is one of the factors which influence the specific energy consumption. Optimizing and brining down of molten metal pouring temperature by 10^0 C can save about 15-20 kWh/t of liquid metal. A higher tapping temperature allowance is given to take care of:

- Heat loss in the ladle
- Heat loss during transit

- Number of openings and carbon content of the steel grade

Heat loss in the ladle: Tapping temperature can be brought down by reducing the heat loss in the ladle. One of the latest developments to minimize heat loss in the ladle is the blanketing of the tapped metal in the ladle by an insulating expendable compound. The advantage of using this compound are reduction in tapping temperature and hence specific electrical energy consumption, uniform temperature of the melt through out etc. Rice husk ash which is very high in silica can also be used to reduce the temperature drop in ladles. This can also be used as insulating filler between the ladle and an outer jacket.

Heat loss during transit: The delay analysis should also be carried out for various stages right from the lifting of ladle from the ladle pre-heating station to the concast area. The delay in lifting ladle will cause substantial drop in ladle temperature thus requiring corresponding increase in tapping temperature. It is advantageous to operate the furnace at the highest voltage level compatible with satisfactory arc stability, so that the current is minimum.

After analyzing the data and implementing the corrective measures of reducing heat loss in ladles and during transit, the standard for tapping temperature should be set so that it is marginally (about 10-20^{0}C) above the sum of liquid temperature and the drop in temperature at various stages between tapping and the last pouring.

Electrode Consumption

In high or ultra high power arc furnaces, electrode costs can account for up to 15% of the conversion cost. In addition, electrode performance substantially affects the operating costs of the furnace. The rising cost of electrodes during recent years have compelled steel maker to devote greater attention the causes of electrode wear. The most important factor is oxidation of the electrode graphite. The oxidation rate is largely dependent on the surface temperature of the electrode and on the velocity, turbulence and oxygen content of the gases lapping it. The most widely used method of reducing surface consumption consist of coating the electrode with an antioxidant.

Improved Casting Yield

Optimized yield of finished casting can reduce energy costs. It can be improved by using computer programme efficient mould designs, ceramic feeder inserts and filters.

Delay analysis

To minimize avoidable delays, it is essential that the reason for the delay be analyzed. For the purpose of delay analysis, the cause of the delay and its duration should be logged for a period of 3-6 months. The data so collected should be arranged in such a fashion that the cumulative delay time for each type of fault, breakdown problem is available at a glance. In this manner, the major problems causing delay can be addressed so that the benefits in the form of reduced energy consumption can accrue.

Foamy Slag practice

Foamy slag practice involves injection of calcium carbonate and carbon powder into the oxygen enriched slag. Calcium carbonate cools the slag by endothermic reaction and the carbon reduces the iron oxide content in the slag and also develops carbon monoxide gas so that the slag swells up. Foamy slag on top of the melt decreases the required energy input by efficient energy transfer and in particular the protection of the furnace shell. Another positive effect of the foamy slag is a reduction in noise caused by the EAF process. It saves refractory material by protecting the furnace lining from extreme heat radiation. This means a lower amount of refractory breaks possibly has to be land filled or treated, it also means a saving of internal input. Foamy slag practice also improves the Fe yield, while reducing the radiative heat losses from the steel bath. On the other hand, foaming slag has a lower density than normal slag (1.15 -1.5 t/m^3 compared to 2.3 t/m^3), so the volume of slag initially obtained increases. It increases productivity and can be considered as a retrofit measure as well as state of the art in modern electric steel making. Therefore the effects of the foaming slag practice are:

- Reduction in energy consumption (10 kWh/t)
- Reduction in electrode consumption (0.7 kg/t)
- Reduction in noise level
- Reduction in melting and refining time
- Improvement in the furnace operating power factor by about 5-10% resulting in reduced distribution losses.
- Increase in productivity

5.1.12 Auxiliaries

Compressed Air System

Compressed air is one of the major auxiliary load in most steel foundries. Excessive pressure drop due to inadequate pipe sizing, choked filter elements, improperly sized coupling and hoses represents energy wastages due to leaking pipe joints and coupling.

Pressure loss in pipe

It is essential that pipes should be sized so as to prevent excessive pressure drop. The following table (Table 3) demonstrate the pressure loss in pipesl.

Table 3 Pressure Losses in Air Mains

Pipe normal bore mm	Pressure drop (bar) per 100 meters	Equivalent power losses kW
40	1.8	9.5
50	0.65	3.4
65	0.22	1.2
80	0.04	0.2
100	0.02	0.1

To avoid excess energy loss, maximum air velocities in pipes should not exceed 6 m/s although higher air velocity can be permitted in branch lines of total length less than15 m. The following table (Table 4) gives the maximum recommended air flow rate for various sizes of pipes at the normal compressed air pressure of 7 bar gauge (100 psig) for both main line piping and branch main of limited length.

Table 4 Maximum Recommended Air Flow Rates

Medium weight pipe BS 1387	Maximum recommended air flow at a pressure of 7 bar gauge (100 psig)	
Normal bore (inch) exceeding 15 m	Main lines (scfm)	Branch lines (scfm)
1/8	3	6
1/4	6	13
3/8	10	29
1/2	20	54
3/4	35	80
1	54	150
1.25	100	315
1.50	135	470
2	220	900
2.50	375	1450
3	500	2600
4	875	—
5	1300	–
6	1900	

Leakage

Another major opportunity to save energy is the prevention of leaks in the compressed air system. Leaks frequently occurs at air receiver relief walls, pipe and hose joints, shut-off valves, quick release couplings, tools and equipment . In most cases, leakages are due to poor maintenance rather than improper installation. The following table (Table 5) gives approximate power wasted by leaks of various sizes at the normal pressure of 7 bar gauge. The leakages can be detected by regular checking of joints, unions etc with soap water.

Table 5: Power Wastage through Leaks

Hole diameter (inches)	Air leakage at 7 bar gauge (scfm)	Power required to compress air being wasted (kW)
1/64	0.4	0.1
1/16	6.5	1.0
1/8	23.2	3.5

There exists a scope for energy conservation in the compressed air system by constant maintenance and rectification of leak prone areas. Clean and dry intake air leads to more efficient compression. For every 4^0C rise in inlet air temperature, 1% extra energy is consumed.

Lighting system

Lighting system offers scope for energy conservation if attention is focused on the following areas:

- Efficient lighting system
- Efficient lighting control

Pumping system

The pumping system should be analyzed for the type of controls provided. In oversized pumps, instead of controlling the discharge by throttling, pump should be de-rated by reducing the size of the impeller, operating the pump at lower speeds.

As constant speed pumps work economically, without undue energy wastage, over a very narrow range near to the design point, one should endeavor to operate the pump as near to the design point as possible, without the use of inefficient controls like throttle valves.

Ladle pre heating

Ladle preheating is an energy intensive process, the oil consumption varying from 10-30 liters/ton. Some of the units use burners which have been fabricated by the plant personnel resulting in inefficient and erratic combustion. Substantial savings in energy are possible by switching over to film burners, by going in for refractory fiber cover on the ladle and a refractory fiber sleeve in the ladle between the shell and refractory brick.

5.1.13 General Practices

Demand management

Managing the maximum demand of the plant within specified limits by means of staggering of loads, shedding non-essential loads during peak hours etc. will bring forth substantial saving in the energy bill.

A measure of the effectiveness of any demand management programme is an index called the load factor which is ratio of actual energy consumption to the consumption if the peak load had continued throughout the day. Improving the load factor by demand management is not an energy conservation measures but it is an effective method of reducing the energy bill by pruning the maximum demand.

Reactive power compensation

The furnaces have different power factor at different stages of operation. Judicious design can overcome the problem of low system power factor.

5.1.14 Financial analysis for energy conservation

A correct investment decision of energy conservation measures can be made by employing financial ratios like payback period, present value method, internal rate of return etc.

5.1.15 Monitoring and Targeting

Monitoring and targeting is an integral part of energy conservation activities. Targets and standards have to be set to achieve energy efficiency. The process will be complete only if the management monitor the results on continual basis.

5.1.16 Opening around the Electrodes

The electrode holes in the roof should have a diameter by 40-50 mm greater than the actual diameter of electrodes in order to prevent damage to the electrodes during heating of the roof. If the gap between the electrodes and roof is more then much heat would be lost with the furnace gases evolving through these gaps. This could involve a high loss of electric energy/heat. In addition, hot gases can heat the electrodes to a temperature above 500^0C at which the electrodes begin to oxidize intensively. There diameter thus diminishes and the current density increase. This can result in electrode fracture, resulting in a higher consumption of electrodes and higher cost of steel produced.

5.1.17 Reduction in number of charging buckets

It has been observed that in most of the electric arc furnaces, the industry is using 2-3 ladles for the transfer of molten metal from electric arc furnace, to refine the molten metal and for casting to concast plant. Whereas in one of the units at Mandi Gobindgarh, the industry is using single ladle for carrying out all these operations. This would help in to reduce the emissions being generated during preheating of the ladle with furnace oil besides savings in consumption in furnace oil.

Number of buckets should be as minimum as possible. To reduce this, number the raw material should be compacted form by using either bundling press or using high density scarp. Reduction of charging buckets will reduce the total pollution being generated during roof opening at the time of charging.

5.1.18 Improvement in Secondary Emission Control System

The following points would help in the improvement of a secondary emission control system:

- The electric arc furnace enclosed building should be as small as possible for good ventilation.
- The structure of a charging crane should be considered so as not to obstruct the ascending stream from the furnace.
- Heat sources in the melt shop should be isolated from the dusting sources e.g. continuous casting area should be isolated from the electric arc furnace area with curtain walls or fixed walls to permit ascending air in the continuous casting area, which is not dusty, to be emitted outside without de-dusting.
- Where canopy hood is provided above the electric arc furnace to contain the secondary emissions, the location of the hood should be such so that it neither obstruct the working of overhead crane nor obstruct the movement of electrodes.

During studies, a similar hood was observed in the electric arc furnace of M/s Hindustan Engg. & Industries Ltd., Hoogly (West Bengal). This hood is placed at a distance of 5'-6' below the over head crane and around 2' above the electrodes. The hood is being operated pneumatically. It neither obstruct the movement of overhead crane nor the movement of electrodes.

5.1.19 Reduction in Electrode Consumption

Graphite electrodes constitute the single biggest consumable in steel making in terms of cost. 10-15% reduction in electrode consumption is possible by adopting water spray system for direct cooling of electrodes, a thin water film cools the surface of the electrode, thus reducing oxidation. Coated graphite electrodes are used to minimize oxidation loss. This coating also provides and electrically conductive outer skin to reduce current density and reduces electrode breakage. Thus specific consumption is reduced by 20-30%.

The electrode consumption gets reduced by 30% when continuous feeding of DRI is applied, compared to the conventional 100% cold scrap charge practice. This is due to higher productivity, decreased electrode oxidation, less frequency of roof opening meaning less thermal shock, less CO in furnace atmosphere and less electrode breakages.

5.1.20 Incorporation of Power Conducting Arms

The present day design of EAFs has incorporated the aluminium box type arms in place of copper clad arms, thus reducing electrical energy losses, electrode consumption and manufacturing costs. With the use of aluminum conducting arms, the arc is more stable, resulting in lower operational reactance and higher active power input.

5.1.21 Productivity

With % DRI in charge below 30%, there has been no increase in productivity. Between 30% to 70% DRI, the gain in productivity is about one tonne per hour for every 10% DRI increase.

The increase in productivity is mainly due to the shortening of conventional refining perid due to overlapping of melting and refining periods.

5.1.22 Fluid coupling with fan of APCD

Generally the fan is installed at the back end of the pollution control system consumes very large amount of power. The flue gas volume varies with variation in temperature of the furnace at different times. It has been observed that the pollution control system which was designed with respect to peak volume when comes to valley (low volume) because of variation in temperature, the efficiency of the fan comes down. The fan was observed to be operating all the time irrespective of whether the furnace was under charging or furnace was under tapping. When the fumes were not generated even then the fan was running continuously, may be with the damper partially closed but consuming fairly good amount of power.

Ne unit at Punjab have installed fluid coupling with the fan so that the speed of the fan can be varied according to the pollution load. As we know that volume of the flue gases is proportional to the speed of the fan, the pressure is proportional to the square of the speed and power consumption is proportional to the cube of the speed. By incorporating this system, the industry have been able to save considerable amount of energy. The fluid coupling is only viable for bigger furnaces having pollution control system ID fan capacity more than 400 HP. The cost of fluid coupling is around 5 lacs. For smaller capacity furnaces, variable speed derive motors can be used.

5.1.23 Electrode cooling

It is very important to fully control the amount of water which is being put on the electrodes for cooling purpose. PLC based temperature sensor should be provided for controlling the amount of water which is totally dependent upon the temperature of the electrodes. Whenever the furnace is off, the water automatically stops and the melter does not have to bother about all these things. Otherwise if the operator forgets to close the valve, then lot of water will go into the furnace and will create a lot of other problems.

5.2 Electric Induction Furnaces

5.2.1 Energy Conservation

The following operational measures can be adopted to reduce the specific energy consumption in induction furnaces.

Idling Period:

Idling periods are the periods when the furnace power is switched off, should be kept as short as possible. Periods of idling are inherent because of the following activities:

Charging:

The charging material must be dry in order to avoid explosions. The most efficient way to charge a furnace is with drop buckets that consume the least time.

Slagging:

Slagging operation is the most energy wasting activity as it is done with power off. The most advantageous method is the back tilt design which results in minimum movement of the slagging door and a maximum back tilt angle without blocking the front of the furnace by ladle traffic.

Sampling:

To conserve heat, samples should be taken through a small sampling cover without opening the complete furnace cover.

Charge Material:

Cleanliness of charge, charge density and charge size are important parameters affecting the energy consumption, charging and de-slagging practice. The volume of slag and build up problems are largely governed by the quality of charge materials. Apart from the cleanliness of charge material, the charge size is also important and has a bearing on the starting characteristics of the furnaces especially those of main frequency. Dirty charge constituents can result in serious de-slagging and built up difficulties. Charge pieces should be at least 8-10" in dia meter because coil efficiency increases rapidly as diameter initial charge increases.

Molten Heel Practice:

The furnace should be operated with a molten heel size of about two third of the furnace capacity, for optimum performance.

Furnace Cover Losses:

Furnace door should be opened for the least minimum time to avoid excessive radiation loss.

5.2.2 Charging and Melting

The main charge materials used in an induction furnace are scrap and ferro alloys. For better and efficient operation of melting, charge should:

- Be as dense as possible.
- Be clean. Rust oil grease sand etc., should preferably be nil.
- Be metallurgically clean, i.e. free from slag lumps, oxides etc., particularly for sponge iron, skull and ferro alloys.

- Have less sharp pointed edges, particularly in case of heavy and bulky scrap.
- Be segregated from harmful ingredients like explosives closed containers evaporative substances and readily available in chargeable sizes on the shop floor.
- During melting there should be certain quality control as well as energy conservation measures. These are:
- First batch of charge should aim for around 0.20 per cent higher carbon in the bath than the final chemistry, at about 30per cent melt level, incase sponge iron is to be added. Otherwise target chemistry is to be maintained.
- Sponge iron charging should be over by around 80 per cent of melt level.
- Obtain bath analysis at 50 per cent melt level for %C & Mn. At this stage %C & Mn should be around 0.20_per cent.
- Continuous deslaging and not to allow slag crust to form. Enrich slag with carbon to Fe from Feo. Maintain a protective cover on the molten metal to avoid ingress of gases.
- Maximum possible continuous operation of the furnace.
- Proper housekeeping and efficient material flow on the furnace bay in particular.
- Continuous charging to maximum possible quantity
- Immediate charging and running of the furnace at full power after tapping. First charging preferably by bucket.
- Always run the furnace at full power.
- Avoid delay in operation changeovers to reduce heat time.
- Avoid excess super heating and bridging.
- Use the furnace lid whenever possible.

5.2.3 Heat Finishing & Tapping

Following measures could be adopted during finishing and tapping of a heat.

- Crate slag free bath.
- Carryout primary de-oxidation by dipping pure aluminum followed by SiMn, wait for 2-3 minutes and then skim off the slag.
- Control minimum tapping temperatures and attain it without holding the molten in the furnace.

- Check plate samples to ensure killing of bath.
- Completely avoid excess superheating.
- Employ smooth tapping and avoid any jerk.
- Ensure close tap stream.

Liquid metal after complete adjustment, cold either by directly poured into the moulds for ingot casting or be taken into a ladle for pouring. Post tapping operations are also important in the light of quality and productivity.

5.2.4 Minimize and control the refractory wall wearing

The refractory life depends on the choice of materials as a function of the slag chemistry (acidic or basic), the operational temperature (steel, cast iron, non-ferrous), and the care taken upon relining (sintering). The lifetime may vary from 30 (steel, cast iron) to 100 – 200 (cast iron) melts. Operational control measures are taken to follow the refractory wear. These include visual inspection, physical measurement and instrumental monitoring programmes. Good charging practice measures prevent the cumulative effects of physical chokes and mechanical stresses. These include the use of automatic charging systems, hot charging, avoiding high drops and the use of compact and dry scrap.

5.2.5 Change from mains frequency to medium frequency furnaces

Medium frequency (250Hz) furnaces have a higher power density (up to 1000 kW/tonne) than mains frequency (50 Hz) furnaces (300 kW/tonne). This allows the use of a smaller crucible (up to a factor of three smaller) which results in a smaller total heat loss. The thermal efficiency of medium frequency furnaces is 10 % higher than for the mains frequency types. Additionally, mains frequency units need to be operated with a molten heel of up to 2/3 of the crucible capacity to optimize specific energy consumption and also require specific starter-blocks for cold start-up. Medium frequency furnaces can readily be started with a cold charge and can be emptied at the end of each working shift or melting batch.

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